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LUMBER GRADE RECOVERY

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ENGELMANN SPRUCE IN COLORADO

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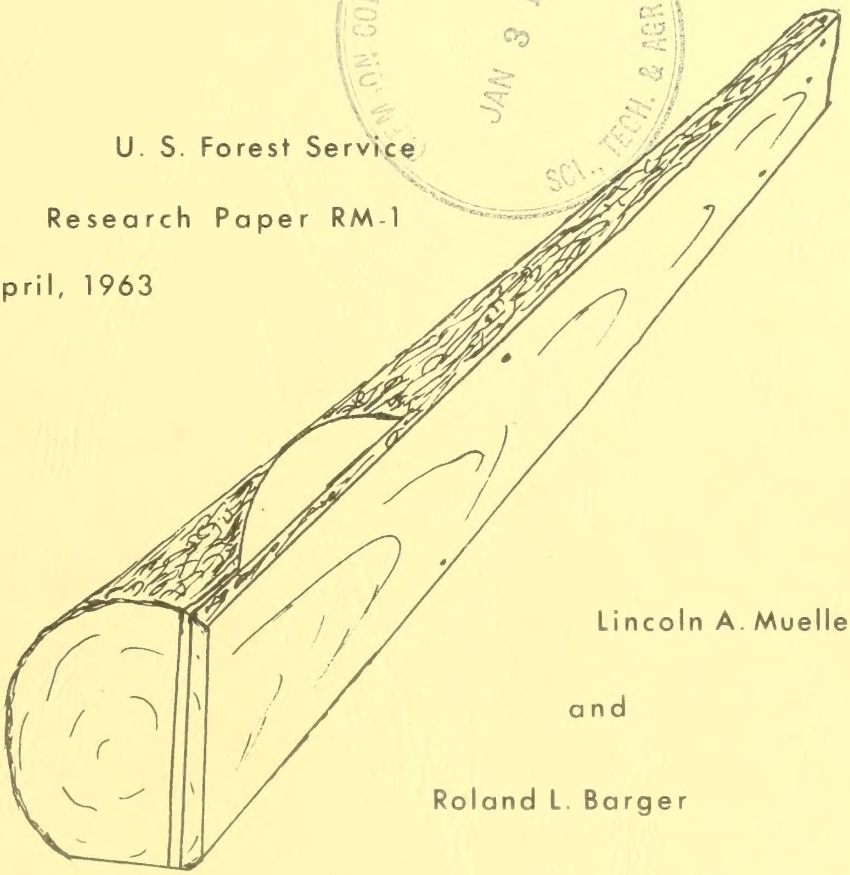
April, 1963



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PLEASE NOTE

This is the first of a new series of reports to be issued by the Rocky Mountain Forest and Range Experiment Station. These reports will be designated "U. S. Forest Service Research Paper RM-__." They replace the Station Paper series, the last one of which was Station Paper 73.

ACKNOWLEDGMENT

This study was made possible through the cooperation and assistance of the Weidman Lumber Company of Durango, Colorado; College of Forestry, Colorado State University; and U. S. Forest Service personnel of the Division of Timber Management, Denver, San Juan National Forest, Durango, and Forest Products Laboratory, Madison, Wisconsin. Dr. Carl Newport, formerly with the CSU College of Forestry, now with the Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, was especially helpful in the analytical phases of the work. E. M. Conway, formerly with the Rocky Mountain Forest and Range Experiment Station, now with the Central States Experiment Station assisted with the field work.

U. S. Forest Service Research Paper RM-1 April 1963

LUMBER GRADE RECOVERY FROM ENGELMANN SPRUCE IN COLORADO

By

Lincoln A. Mueller and Roland L. Barger, Technologists

Rocky Mountain Forest and Range Experiment Station[1]

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[1] Central headquarters maintained in cooperation with Colorado State University, Fort Collins.

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LUMBER GRADE RECOVERY FROM ENGELMANN SPRUCE IN COLORADO

By

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INTRODUCTION

Engelmann spruce (*Picea engelmannii* Parry) is Colorado's most important sawtimber species. It makes up approximately 50 percent of the total sawtimber volume, and 40 percent of the growing stock. The species is recognized for its straight, well-rounded boles, and light-weight, soft-textured wood. It is well adapted to a wide range of uses, both as a building material and as a source of fiber. Heavy utilization of more accessible pine stands during and after World War II shifted emphasis to Engelmann spruce as a primary source of sawtimber. With increased utilization came recognition of its many desirable properties, which progressively strengthened demand.

Engelmann spruce occurs at the higher elevations in the mountains of Colorado. The generally higher logging costs associated with such sites, plus an overall increase in manufacturing costs, have created an increasing need for better stumpage pricing data. The major objective of this study was, therefore, to determine the lumber volume and grade yields currently being recovered from Engelmann spruce sawtimber available to the industry. A secondary objective was to test the feasibility of grading Engelmann spruce logs by application of a set of trial log grades developed for associated species in the Pacific Northwest region.

METHODS

MILL SELECTION

The study was conducted at the J. Stanley Weidman Lumber Company sawmill at Durango, Colorado, in 1957. This milling firm, one of the major spruce lumber producers in the State, produces a full range of standard lumber grades.[2] The stands supplying this mill represent the quality of Engelmann spruce sawtimber available in Colorado.

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[2] Western Pine Association. Standard grading rules for .... Engelmann spruce .... lumber. 141 pp., illus. Portland 4, Oregon. 1957.

The sawmill is equipped with a 6-foot single-cut band headrig and a vertical band resaw. Logs are stored in a pond. Lumber is green graded and sorted by grade and width as it leaves the mill on the green chain to facilitate seasoning, yard inventory, and surfacing. The lumber is air dried in piles that have been carefully stacked and stickered. Pile covers are not used, although select and high-common grade piles are partially protected by a top course of cull lumber. Dried, surfaced lumber is graded by certified Western Pine Association graders.

LOG SAMPLE

To meet the study objectives and have as nearly as possible a random sample of logs from the timber available, arrangements were made to have logs delivered from four landings in a sale area on the San Juan National Forest. The logs were delivered to the mill in both long and short lengths. Long logs were bucked to length upon entrance to the mill. Of 675 logs selected, 621 were 16 feet in length, and 54 were shorter.

LOG SCALING, DIAGRAMING, AND GRADING

All logs were scaled by a recently checked Forest Service scaler in accordance with the 1956 revision of the National Forest Scaling Handbook[3] (Scribner Decimal C Log Rule).

Logs were diagramed by a member of the Forest Products Laboratory staff, who followed the diagraming system adopted by the Laboratory.[4] Due to the layout of the mill, it was necessary to diagram the logs on the jackladder. White fir (Abies concolor (Gord. & Glend.) Lindl.) logs intermixed with the spruce study logs provided additional time to complete diagraming. The down face was diagramed as the log was ejected from the conveyor to the mill deck.

Grading was done by personnel of the Rocky Mountain Station, who worked closely with the log diagraming operation. The logs were graded according to the trial log grades developed in the Pacific Northwest, Region 6, for associated species. (appendix, page 19.) The minimum diameter limits specified by the grading system were reduced to fit the diameter range common in Engelmann spruce, and knot size limits were extended to include 10-inch grade 3 logs.

MILL PROCEDURE

As the study logs entered the mill, they were assigned consecutive mill log numbers. These numbers were cross referenced with the scale log numbers to identify scale and grade of the logs. The mill log numbers were posted in the mill in a position readily visible to all lumber markers. Sawing instructions specified that the mill follow normal sawing and log break-down practices.

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[3] U. S. Forest Service. National Forest scaling handbook. 119 pp. 1956 revision.

[4] U. S. Forest Service. Sawlog grades for hardwoods -- Central States studies. Forest Prod. Lab. Rpt. D 1699, 22 pp., illus. 1947.

Lumber markers were positioned throughout the mill so that each board from a given log could be properly identified with the mill log number. Upon reaching the green chain, the lumber from the study logs was pencil trimmed and ripped, and graded by a certified Western Pine Association lumber grader. It was then tallied by mill log number, lumber grade, and dimension. The lumber moved from the green chain to the drying yard for air drying.

Later, samples of dry lumber from each grade and width were selected for a study of grade change and volume loss as a result of drying and surfacing. The sample included lumber produced from logs other than study logs, but from the same general area and sawn under the same conditions. This lumber was regraded and tallied after surfacing and end trimming. The resulting change-of-grade and volume-loss factors were applied to green recovery data to obtain the estimated dry surfaced recovery.

In addition to grade and volume recovery data, the time required to saw each log was recorded. Board thickness measurements were also made on a sample of 4/4 boards as a check of sawing accuracy.

ANALYSIS

Electronic data processing methods were used in compiling the study data. Log characteristics from the log diagram and scale sheets, and lumber grade and volume data from the mill tally sheets, were punched directly on data processing cards. These cards were processed to obtain green lumber grade and volume recovery by specified log groups and classes.

Green lumber grade recovery was converted to dry surfaced recovery by applying the grade-change and volume-loss factors developed in the degrade study. An IBM 650 program developed for this purpose was employed.[5] This program also computed individual log value, based on 1959 lumber grade selling values. A second IBM 650 program was employed to compute regressions of log volume and value on log diameter, and average value per M board feet.[6]

RESULTS

LOG SAMPLE

A total of 675 merchantable logs were used in the study. Of these, 621 were 16 feet in length and 54 were shorter. Logs scaled as sound made up 84 percent of the sample, or 567 logs. The diameter distribution of the study logs is shown in figure 1. Log scaling diameters ranged from 7 to 27 inches. The average scaling diameter was 12.4 inches, while the most frequently occurring diameter was 11.0 inches.

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[5] Newport, C. A., and Leach, Joe. A method for the application of change in grade factors to individual logs .... an IBM 650 program. U. S. Forest Serv. Pacific Southwest Forest and Range Expt. Sta., Tech. Paper 41. 9 pp. 1959.

[6] Frazier, George D., and Carney, Ronald B. Computing average log values for timber appraisals using IBM 650 or Univac Solid State 80 computers. U. S. Forest Serv. Pacific Southwest Forest and Range Expt. Sta., Tech Paper 54. 16 pp., illus. 1961.

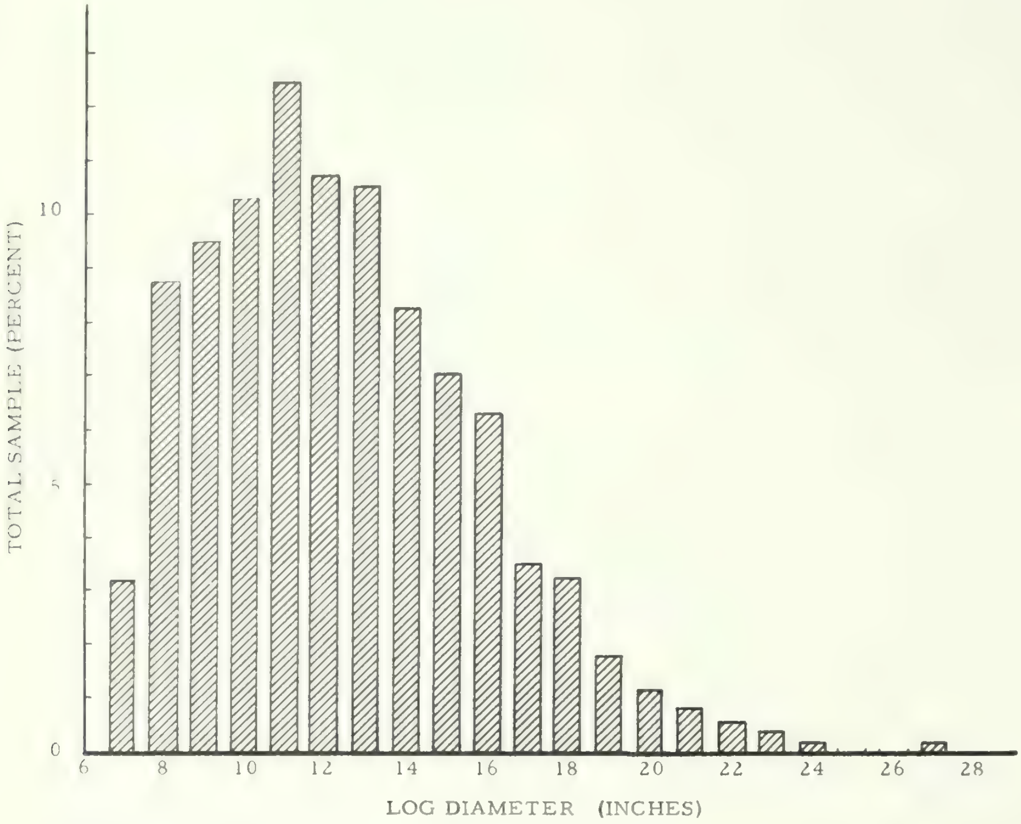

Figure 1. --Diameter distribution of study logs.

LOG SCALE AND DEFECT

The study logs yielded a gross scale of 66,040 board feet. Deduction for defect which amounted to 2,970 board feet or 4.5 percent of total gross scale, left a total net scale of 63,070 board feet. Defect deduction accounted for 24.5 percent of the gross scale of defective (partial-scale) logs. Table 1 shows gross and net scale and percent scale deduction by log grade and log diameter class.

Table 2 indicates amount and type of defect deduction by log diameter class. The relation of diameter to percent of defect is not so pronounced as might be anticipated. Western red rot or heart rot (Polyporus anceps), the principal defect encountered, contributed 44 percent of the total scaling deduction (table 3). Sweep and crook, second in importance, made up 29 percent of the deducted volume. Sap rot and shake accounted for 11 and 9 percent, respectively, with check and split making up the bulk of the remaining 7 percent. A small amount of defect was borderline between heart rot and sap rot.

Table 1.--Gross and net volume of study logs by log grade and log diameter class — all logs

Log grade and log diameter	Logs	Scribner scale		Scale deduction
		Gross	Net	
	Number	Board feet		Percent
LOG GRADE:				
1	3	880	870	1.1
2	47	9,410	8,730	7.2
3	323	39,710	38,000	4.3
4	302	16,040	15,470	3.6
Total	675	66,040	63,070	4.5
LOG DIAMETER (Inches):				
7	22	650	620	4.6
8	60	1,710	1,690	1.2
9	65	2,530	2,510	.8
10	71	4,060	3,850	5.2
11	85	5,700	5,400	5.3
12	73	5,720	5,520	3.5
13	71	6,970	6,860	1.6
14	56	6,120	5,990	2.1
15	48	6,690	6,470	3.3
16	43	6,780	6,480	4.4
17	24	4,240	4,020	5.2
18	22	4,540	4,220	7.0
19	12	2,880	2,600	9.7
20	8	2,240	2,110	5.8
21	6	1,800	1,760	2.2
22	4	1,320	1,020	22.7
23	3	1,140	1,060	7.0
24	1	400	390	2.5
27	1	550	500	9.1
Total	675	66,040	63,070	4.5

With respect to log position, scale deductions accounted for 7.4 percent of the gross scale of butt logs, 3.6 percent of middle logs, and 2.3 percent of top logs. All deduction in top logs was for sweep or crook. Table 3 shows type and amount of scale deduction by log position, as determined by the scaler.

Table 2. --Gross scale deductions by defect type and log diameter class -- all logs

Log diameter (inches)	Logs	Defect type						Total scale deduction
		Heart rot	Sap rot	Heart and sap rot	Check or split	Sweep or crook	Shake	
	Number	Percent						
7	22	0	0	0	0	4.6	0	4.6
8	60	0	0	0	0	1.2	0	1.2
9	65	0	0	0	0	.8	0	.8
10	71	2.2	0	0	0	3.0	0	5.2
11	85	.7	0	0	0	4.6	0	5.3
12	73	.9	.5	0	0	1.8	.3	3.5
13	71	.3	.3	0	0	1.0	0	1.6
14	56	1.0	0	.3	.5	.3	0	2.1
15	48	2.4	.6	0	0	0	.3	3.3
16	43	2.5	.6	0	0	.7	.6	4.4
17	24	2.8	.5	0	.5	1.2	.2	5.2
18	22	1.3	2.7	0	.4	.4	2.2	7.0
19	12	7.0	1.0	0	.7	0	1.0	9.7
20	8	4.0	0	0	.9	.9	0	5.8
21	6	0	0	0	2.2	0	0	2.2
22	4	17.4	0	0	0	3.0	2.3	22.7
23	3	3.5	0	0	3.5	0	0	7.0
24	1	2.5	0	0	0	0	0	2.5
27	1	0	9.1	0	0	0	0	9.1
Total	675	2.0	.5	0	.3	1.3	.4	4.5

Table 3. --Gross scale deductions by defect type and log position

Defect type	Log position[1]				Proportion of total defect
	Butt	Middle	Top	All	
	Percent of gross scale				Percent
Heart rot	3.4	1.8	0	2.0	44.4
Sap rot	.9	.4	0	.5	11.1
Heart and sap rot	0	0	0	0	([2])
Check or split	.3	.2	0	.3	6.7
Sweep or crook	2.4	.8	2.3	1.3	28.9
Shake	.4	.4	0	.4	8.9
Total	7.4	3.6	2.3	4.5	100.0

[1] Log position analysis is based upon defect data from 672 logs.

[2] Less than 0.1 percent.

LUMBER GRADE CHANGE AND VOLUME LOSS

A lumber sample of 33,073 board feet was used to determine the change of grade and volume loss as a result of drying, surfacing, and end trimming. The sample included lumber of all available widths in each lumber grade. Table 4 indicates the distribution of the sample by grade and nominal width.

The lumber was air dried to a moisture content of 12 to 15 percent. Careful stacking and stickering, and adequate pile foundations, minimized warping, cupping, and other deformation. Pile covers were not used, although select and high-common grade lumber was protected by a top course of cull lumber.

The sample lumber was regraded and tallied after surfacing and end trimming. The resulting volume loss and grade changes are shown in tables 4 and 5. Because of the small volume involved, the select grades were combined in the green grade. Dimension lumber made up only 0.8 percent of green volume recovery, and was not represented in the degrade study.

The change-of-grade and volume-loss factors shown in table 5 were applied to green grade recovery to obtain estimated dry surfaced lumber grade recovery. This resulted in an 8.7 percent reduction in the total green volume of lumber in the recovery study.

Table 4. --Degrade lumber sample and related drying and surfacing volume losses

Green grade	Board width	Green volume	Finished volume combined grades	Volume loss
	Inches	- - - - Board feet	- - - -	Percent
Select	8	2,963	2,744	7.39
1-2 C	12	3,908	3,688	5.63
	10	1,528	1,422	6.94
	8	4,315	4,160	3.59
	6	3,895	3,745	3.85
3 C	12	1,848	1,626	12.01
	10	1,495	1,332	10.90
	8	5,767	5,237	9.19
	6	1,061	1,013	4.52
4 C	12	1,566	1,376	12.13
	10	1,132	940	16.96
	8	1,472	1,241	15.69
	4	1,157	976	15.64
5 C	12	272	226	16.91
	10	303	232	23.43
	8	213	164	23.00
	6	178	126	29.21

[1] Most losses were due to checking associated with spiral grain.

Table 5. --Change of lumber grade and volume loss[1] from green to dry surfaced condition

Green grade	Dry surfaced grade								Volume loss
	Select			Common					
	B and better	C	D	1-2	3	4	5	Dimension	
	Percent of green volume								
Select	51.80	10.34	16.60	1.31	3.29	6.12	3.15	0	7.39
1-2 C	0	0	0	49.94	38.38	6.86	.19	0	4.63
3 C	0	0	0	7.01	65.87	16.87	.78	0	9.47
4 C	0	0	0	.23	6.86	72.77	5.24	0	14.90
5 C	0	0	0	0	.32	12.97	64.11	0	22.57
Dimension	0	0	0	0	0	0	0	100.00	0

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[1] Largely from checking associated with spiral grain.

LUMBER VOLUME RECOVERY AND OVERRUN

The study logs yielded 73,558.8 board feet of rough lumber. Computed volume losses due to drying, surfacing, and end trimming reduced total recovery to 67,150.4 board feet. Log scale and lumber recovery values for the average study log are as follows:

	Board feet
Gross scale	97.8
Net scale	93.4
Green recovery	109.0
Finished recovery	99.5

Table 6 shows green and dry surfaced lumber recovery, and overrun, by log diameter class.

All overrun values are computed on the basis of dry surfaced lumber recovery. As generally expected, partial-scale logs yielded consistently higher overruns than did full-scale logs of comparable size, largely because portions of the deducted volumes are frequently recovered in the sawing operation. Also, hidden defect in full-scale logs reduces lumber yield below scaled volume. Overrun by 1-inch log diameter classes followed the irregular pattern that is typical of the Scribner Decimal C log rule, and declined as diameter increased. Figure 2 illustrates this trend for both full-scale and partial-scale logs.

Table 6.--Net log scale, lumber recovery, and overrun,[1] by log diameter class

Log diameter (inches)	Logs	Net Scribner scale	Lumber recovery		Overrun[1]
			Rough	Finished	
	Number	Board feet	Board feet		Percent
			All ~~FULL-SCALE~~ LOGS		
7	22	620	686.0	631.7	1.9
8	60	1,690	2,327.5	2,105.8	24.6
9	65	2,510	3,058.7	2,787.3	11.0
10	71	3,850	4,186.0	3,839.1	-.3
11	85	5,400	6,022.6	5,505.2	1.9
12	73	5,520	6,977.5	6,415.6	16.2
13	71	6,860	7,986.4	7,313.5	6.6
14	56	5,990	7,520.9	6,889.8	15.0
15	48	6,470	7,452.6	6,833.0	5.6
16	43	6,480	7,538.3	6,871.2	6.0
17	24	4,020	4,601.6	4,196.2	4.4
18	22	4,220	4,906.6	4,435.6	5.1
19	12	2,600	3,066.0	2,781.0	7.0
20	8	2,110	2,153.6	1,953.0	-7.4
21	6	1,760	1,868.2	1,722.6	-2.1
22	4	1,020	1,265.1	1,117.8	9.6
23	3	1,060	1,132.3	1,035.7	-2.3
24	1	390	398.5	371.6	-4.7
27	1	500	410.4	344.7	-31.1
Total	675	63,070	73,558.8	67,150.4	
			~~PARTIAL~~-SCALE LOGS Full		
7	20	590	627.0	576.9	-2.2
8	59	1,670	2,296.7	2,076.9	24.4
9	63	2,450	2,965.6	2,704.7	10.4
10	60	3,400	3,510.0	3,227.2	-5.1
11	68	4,500	4,885.4	4,487.0	-.3
12	61	4,760	5,893.9	5,444.4	14.4
13	65	6,370	7,312.5	6,699.0	5.2
14	50	5,460	6,739.8	6,176.7	13.1
15	41	5,710	6,377.0	5,843.3	2.3
16	31	4,880	5,472.1	4,991.7	2.3
17	14	2,440	2,698.5	2,448.4	.3
18	15	3,070	3,384.4	3,075.6	.2
19	7	1,680	1,751.0	1,607.1	-4.3
20	5	1,400	1,340.4	1,236.2	-11.7
21	5	1,500	1,566.6	1,445.3	-3.6
22	1	330	354.0	321.9	-2.5
23	2	760	786.4	719.4	-5.3
24	0	0	0	0	0
27	0	0	0	0	0
Total	567	50,970	57,961.3	53,081.7	
			~~ALL~~ LOGS		
7	2	30	59.0	54.8	82.7
8	1	20	30.8	28.9	44.5
9	2	60	93.1	82.6	37.7
10	11	450	676.0	611.9	36.0
11	17	900	1,137.2	1,018.2	13.1
12	12	760	1,083.6	971.2	27.8
13	6	490	673.9	614.5	25.4
14	6	530	781.1	713.1	34.5
15	7	760	1,075.6	989.7	30.2
16	12	1,600	2,066.2	1,879.5	17.5
17	10	1,580	1,903.1	1,747.8	10.6
18	7	1,150	1,522.2	1,360.0	18.3
19	5	920	1,315.0	1,173.9	27.6
20	3	710	813.2	716.8	1.0
21	1	260	301.6	277.3	6.7
22	3	690	911.1	795.9	15.3
23	1	300	345.9	316.3	5.4
24	1	390	398.5	371.6	-4.7
27	1	500	410.4	344.7	-31.1
Total	108	12,100	15,597.5	14,068.7	

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[1] Overrun is based on dry surfaced lumber recovery.

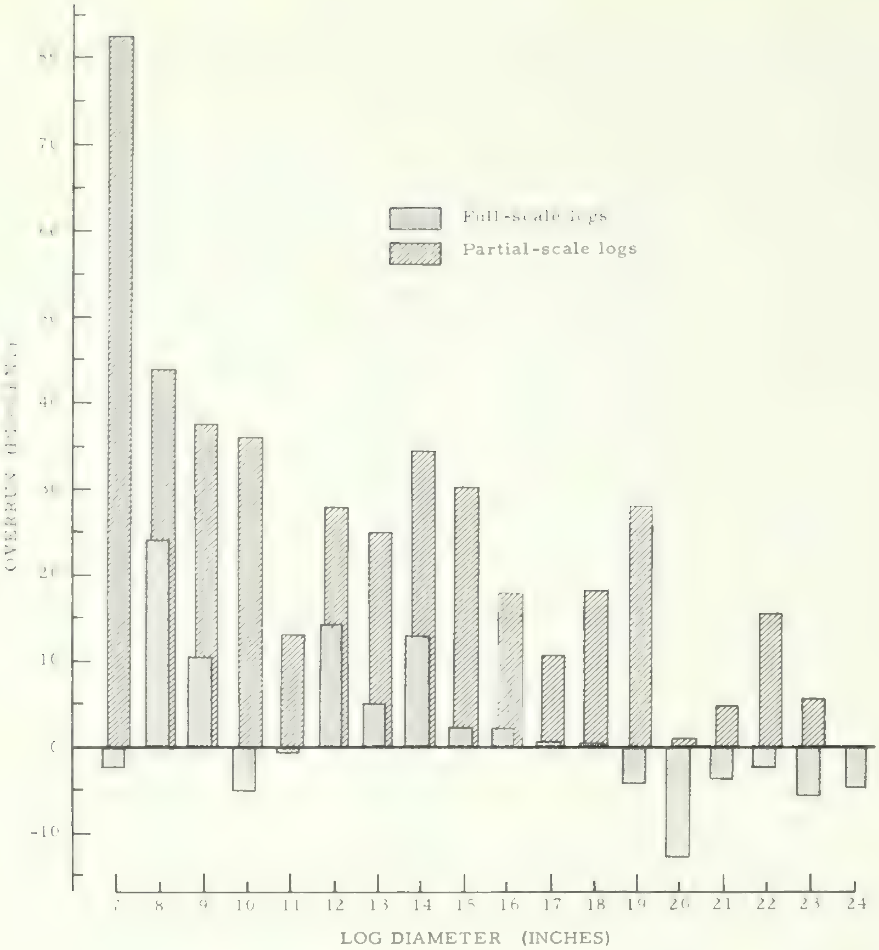


Figure 2. --Overrun by log diameter, based upon dry surfaced lumber recovery.

ESTIMATED LUMBER VOLUME RECOVERY

Average lumber volume recovery, when computed from study data for each log diameter class and grade, may be somewhat erratic. This is partially due to log diameter classes and grades that are inadequately represented, because of the inherent nature of the timber involved. It may also be partially ascribed to chance variation in the sample of logs selected. Consequently, average recovery volume can be estimated more reliably by statistical methods than from the raw data.

Lumber volume recovery was estimated by computing regressions that related individual log volume to log scaling diameter. Separate regressions were computed for each log grade, scaling class (full-scale, partial-scale, and all), and log-length class (16-foot and shorter). Regression estimates of dry surfaced lumber recovery are shown by log grade, scaling class, and diameter class in table 10, appendix. There were too few logs in grade 1 to warrant regression analysis.

All regressions were second-degree polynomials of the type $Y = a + bX + cX^2$, where Y = recovery volume and X = log scaling diameter. Standard error of estimate ($S_{y.x}$) for the regressions ranged from 9.9 to 25.8 board feet. Coefficients of determination (R^2) ranged from 0.78 to 0.95.

LUMBER GRADE RECOVERY

An important objective was to determine the lumber grade distribution of dry surfaced lumber recovered. Table 7 summarizes lumber grade recovery both by log grade and log diameter class. Lumber grade recovery is expressed as a percent of total recovery.

The high proportion of common grade lumber, characteristic of Engelmann spruce, is somewhat compensated for by the small volume in low-common grades. Common grades 1-2 and 3 account for 70.5 percent of total lumber recovery. Knots, although numerous, are for the most part small and sound, and seldom degrade the lumber seriously. The volume of grade 5 common lumber developed is due primarily to the presence of rot.

Select grade lumber recovery shows a general increasing trend with increase in log diameter, although no trends are apparent in common grade recovery. Generally, the smaller logs are top logs and therefore are more heavily limbed than larger logs.

Tables 11, 12, 13, and 14 of the appendix present lumber grade recovery by log grade, scaling class, diameter class, and length.

Table 7. --Percentage lumber grade recovery, dry finished basis, by log grade and log diameter class -- all logs

Log grade and log diameter	Logs	Select grades			Common grades					Total
		B and better	C	D	1-2	3	4	5	Dimension	
	Number	Percent								
LOG GRADE:										
1	3	19.0	3.8	6.1	21.9	31.2	13.7	1.8	2.5	100
2	47	5.9	1.2	1.9	21.1	46.2	20.6	1.8	1.3	100
3	323	1.4	.3	.4	22.2	49.4	23.7	2.2	.4	100
4	302	.6	.1	.2	18.4	51.9	25.3	2.0	1.5	100
Total	675									
LOG DIAMETER (Inches):										
7	22	0	0	0	10.1	42.3	19.3	3.8	24.5	100
8	60	0.3	0.1	0.1	16.8	49.3	29.4	2.4	1.6	100
9	65	.5	.1	.2	19.5	53.9	23.4	1.8	.6	100
10	71	.2	0	.1	24.2	52.4	21.5	1.3	.3	100
11	85	1.3	.3	.4	23.3	49.1	23.6	2.0	0	100
12	73	.9	.2	.3	26.1	50.1	20.7	1.4	.3	100
13	71	1.0	.2	.3	23.9	50.6	22.3	1.6	.1	100
14	56	.9	.2	.3	22.1	54.7	20.3	1.3	.2	100
15	48	3.2	.6	1.0	22.8	49.8	20.7	1.7	.2	100
16	43	2.4	.5	.7	20.2	50.2	24.3	1.7	0	100
17	24	4.0	.8	1.3	18.8	50.2	22.1	2.3	.5	100
18	22	2.0	.4	.6	17.5	47.0	27.5	3.9	1.1	100
19	12	1.9	.4	.6	17.0	47.8	27.9	2.3	2.1	100
20	8	3.8	.8	1.2	18.1	46.4	24.9	3.9	.9	100
21	6	3.5	.7	1.1	25.9	49.2	18.4	1.2	0	100
22	4	3.7	.7	1.2	7.9	32.4	48.0	4.5	1.6	100
23	3	10.3	2.1	3.3	13.1	35.2	25.0	2.1	8.9	100
24	1	30.4	6.1	9.7	16.3	18.8	10.7	2.2	5.8	100
27	1	0	0	0	.2	7.1	76.5	16.2	0	100
Total	675									

LOG AND LUMBER VALUE

Individual log value was computed by means of the Newport-Leach IBM 650 program mentioned earlier. The program applied current lumber grade selling prices to the lumber grade and volume recovery of each study log as shown below:

Lumber grade	Value per M b.m. (Dollars)
B and better select	151.20
C select	151.20
D select	151.20
1-2 common	92.92
3 common	71.61
4 common	67.36
5 common	42.67
2 and better dimension	83.19
3 and better dimension	80.56

All dimension material encountered in the study was valued as grade 3 and better.

These log values were used as observations in regressions calculated to obtain estimated log value. Regressions that related individual log value to log scaling diameter were computed in the same manner as those previously computed for volume recovery. Regression estimates of individual log value are shown in table 10, appendix. Again, grade 1 logs were excluded from regression analysis.

Standard error of estimate ($S_{y.x}$) for the log value regressions ranged from \$0.87 to \$3.47. Coefficients of determination (R^2) ranged from 0.58 to 0.88.

Lumber value per M b.m. for each class of logs was computed by the procedure outlined in the Frazier-Carney IBM 650 program. In this procedure, regression estimates of log value are used in conjunction with estimated lumber recovery to obtain value per M b.m. Lumber values thus computed are shown by log grade, scaling class, diameter class, and length in tables 11, 12, 13, and 14, appendix.

RESULTS OF GRADING ENGELMANN SPRUCE LOGS

Log grading systems, when adequate for the species, form an effective basis for more accurate timber quality appraisal and pricing. One of the objectives of this study was to test the feasibility of grading Engelmann spruce saw logs.

The study logs were graded by means of a modification of the trial log grades developed for associated species in the Pacific Northwest region (appendix, page 19) The minimum diameter limits specified in the grading system were reduced to fit the diameter range common in Engelmann spruce. Knot size limits were extended to include 10-inch grade 3 logs.

Table 8 shows the grade distribution of study logs, and presents lumber recovery and overrun by log grade. Log grades 2, 3, and 4 are well represented, but grade 1 does not contain enough logs for valid comparison with the other grades.

That some quality separation was obtained through grading the logs is apparent in the lumber grade recovery pattern (table 12; and fig. 3). The recovery of select and low-common lumber varies with log grade (fig. 3). Lower grade logs produce proportionately more grade 4 and 5 common lumber, and less select lumber. The proportion of grades 1-2 and 3 common lumber produced remains relatively constant.

Lumber value for each log grade-diameter class was computed from regression estimates of lumber recovery and log value, as discussed previously. Figures 4 and 5 illustrate the resulting lumber value curves for each log grade.

Table 8. --Net log scale, lumber recovery, and overrun, by log grade

Log grade	Logs	Net Scribner scale	Lumber recovery		Overrun[1]
			Rough	Finished	
	Number	- - - - -	Board feet	- - - - -	Percent
		FULL-SCALE LOGS			
1	2	480	522.8	484.4	0.9
2	30	6,000	6,690.0	6,159.1	2.7
3	269	30,960	35,472.7	32,508.5	5.0
4	266	13,530	15,275.8	13,929.7	3.0
Total	567	50,970	57,961.3	53,081.7	
		PARTIAL-SCALE LOGS			
1	1	390	398.5	371.6	-4.7
2	17	2,730	3,477.8	3,164.9	15.9
3	54	7,040	9,053.3	8,141.1	15.6
4	36	1,940	2,667.9	2,391.1	23.3
Total	108	12,100	15,597.5	14,068.7	
		ALL LOGS			
1	3	870	921.3	856.0	-1.6
2	47	8,730	10,167.8	9,324.0	6.8
3	323	38,000	44,526.0	40,649.6	7.0
4	302	15,470	17,943.7	16,320.8	5.5
Total	675	63,070	73,558.8	67,150.4	

[1] Overrun based on dry surfaced lumber recovery.

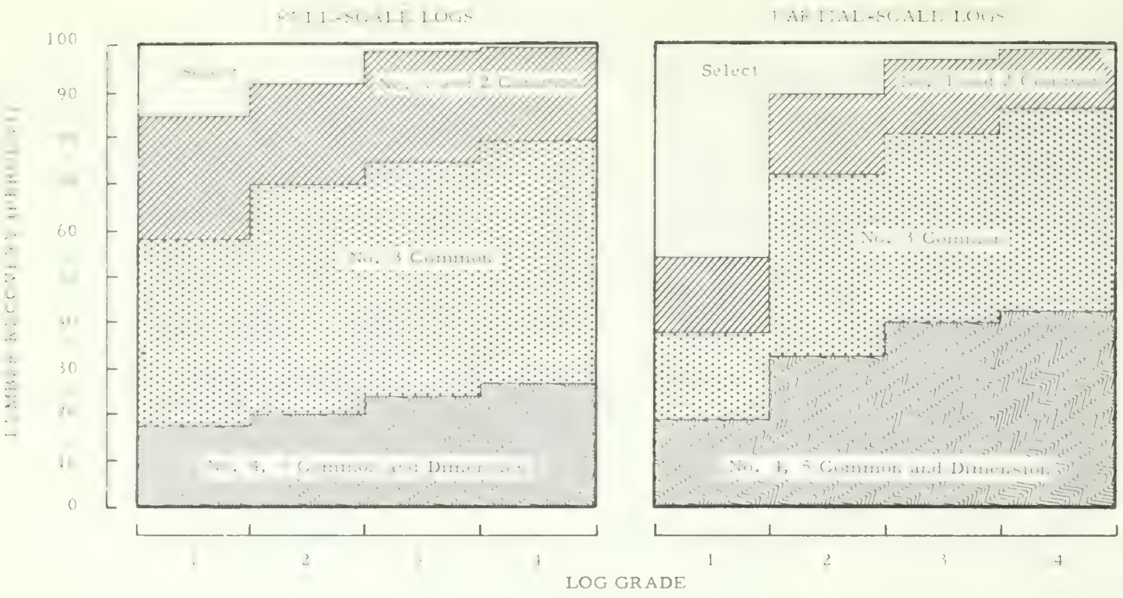


Figure 3. --Lumber grade recovery, dry surfaced basis, by log grade -- 16-foot logs.

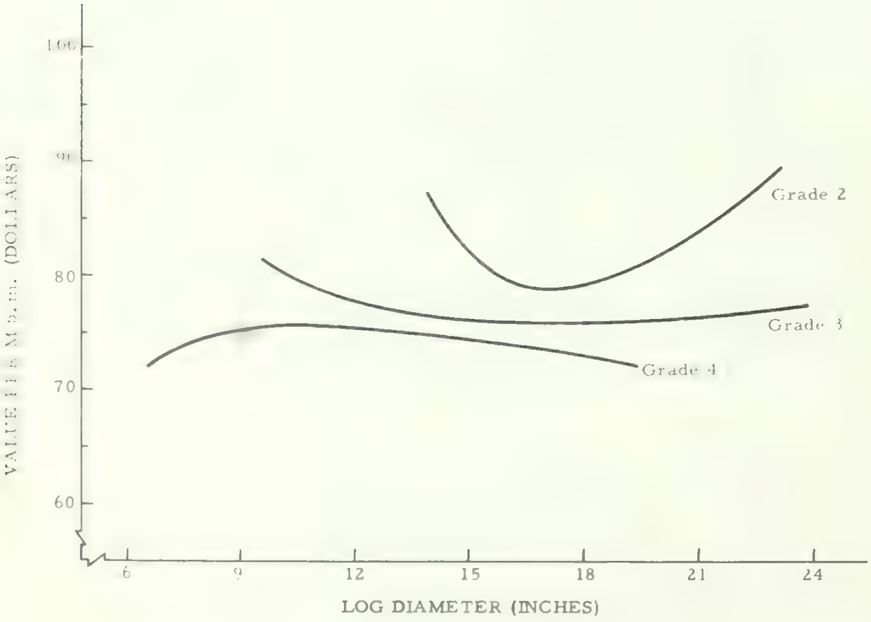
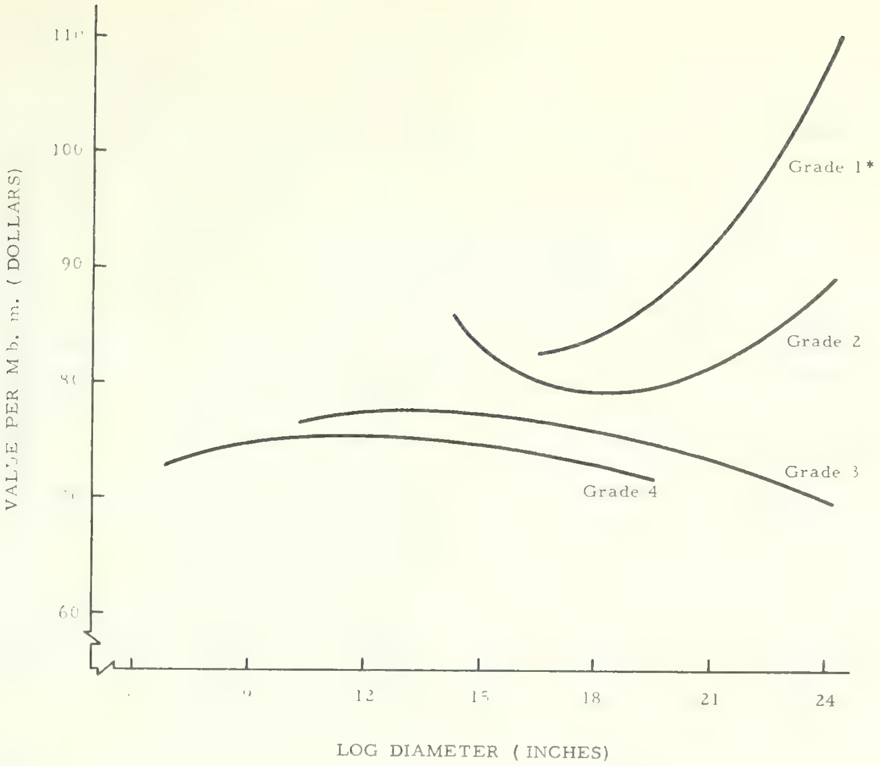


Figure 4. --Average value per M b.m. dry surfaced lumber, by log grade and diameter class--full-scale 16-foot logs.



* Grade 1 curve is freehand, based upon three logs only.

Figure 5. --Average value per M b. m. dry surfaced lumber, by log grade and diameter class--all 16-foot logs.

Diameter classification accomplishes very nearly as much quality separation as does log grading for logs up to 14 inches in diameter. This would be expected, since diameter predetermines to a certain extent the grade of smaller diameter logs. In the larger diameter classes, where the full range of log grades is applicable, logs can be separated as to quality by means of the log grade system. To the extent that quality separation is achieved, log grading appears to warrant further consideration.

Detailed lumber volume and grade recovery, and log and lumber value, are presented by log grade in tables 10 through 14 of the appendix.

LOG SAWING TIME

The headsaw time required per unit of lumber increases as log size decreases. To determine this diameter-sawing time relationship for Engelmann spruce, sawing time was recorded for 669 study logs. Variable sawing time (actual time on the carriage) was subtracted from total elapsed time to obtain fixed time. Fixed time was pro-rated equally among the logs, since log size does not materially affect handling and loading time. Table 9 shows variable, fixed, and total sawing time per log, and sawing time per M b.m., by log diameter. Figure 6 illustrates graphically the relationship between log size and sawing time. The curves are based upon a regression of sawing time on log diameter.

Table 9. --Average sawing time per log and per M b.m. dry surfaced lumber -- 669 logs

Log diameter (Inches)	Logs	Sawing time per log			Sawing time per M b.m.[1]
		Variable	Fixed	Total	
	Number	- - - - - - -	- - - - - - -	Minutes	- - - - - - -
7	22	0.434	0.062	0.496	17.274
8	60	.474	.062	.536	15.272
9	64	.545	.062	.607	14.155
10	69	.573	.062	.635	11.744
11	84	.710	.062	.772	11.920
12	73	.943	.062	1.005	11.435
13	71	1.055	.062	1.117	10.844
14	55	1.130	.062	1.192	9.689
15	47	1.250	.062	1.312	9.217
16	43	1.321	.062	1.383	8.655
17	24	1.518	.062	1.580	9.036
18	22	1.575	.062	1.637	8.118
19	12	1.538	.062	1.600	6.904
20	8	1.970	.062	2.032	7.270
21	6	1.983	.062	2.045	7.123
22	3	2.413	.062	2.475	8.856
23	3	2.843	.062	2.905	8.416
24	1	3.430	.062	3.492	9.397
27	1	3.170	.062	3.232	9.376

[1] Computed averages, based upon average number of logs per M b.m. dry surfaced lumber.

SAWING ACCURACY

A sample of the 4/4 lumber produced was measured to determine the dimensional variation. Three board thickness measurements were taken along the length of each of 198 sample boards. Measurements, taken at board midpoint and 2 feet from each end, were alternated between board edges, and averaged to obtain board average thickness. Figure 7 shows the range of board thickness encountered in the sample, and the proportion of boards in each thickness class.

The board average thickness that occurred most frequently was the target thickness of 34/32 inches; it accounted for 25 percent of the lumber sampled. The eight most frequented consecutive thickness classes (31/32 through 38/32 inches), representing a total spread of 1/4 inch, contain 94 percent of the sample lumber.

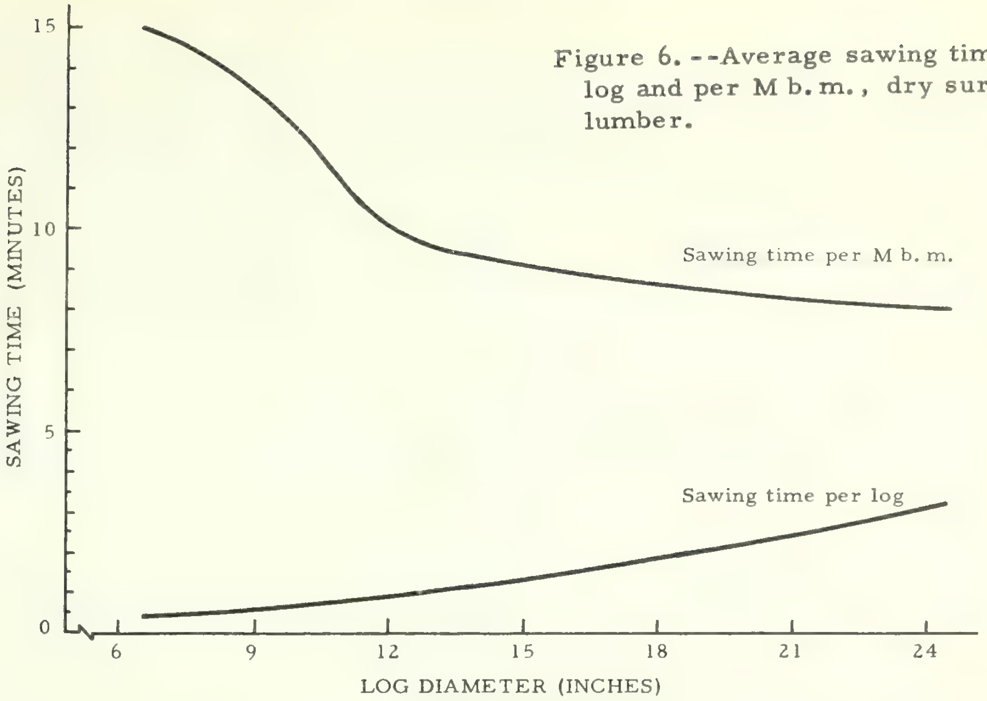


Figure 6. --Average sawing time per log and per M b. m., dry surfaced lumber.

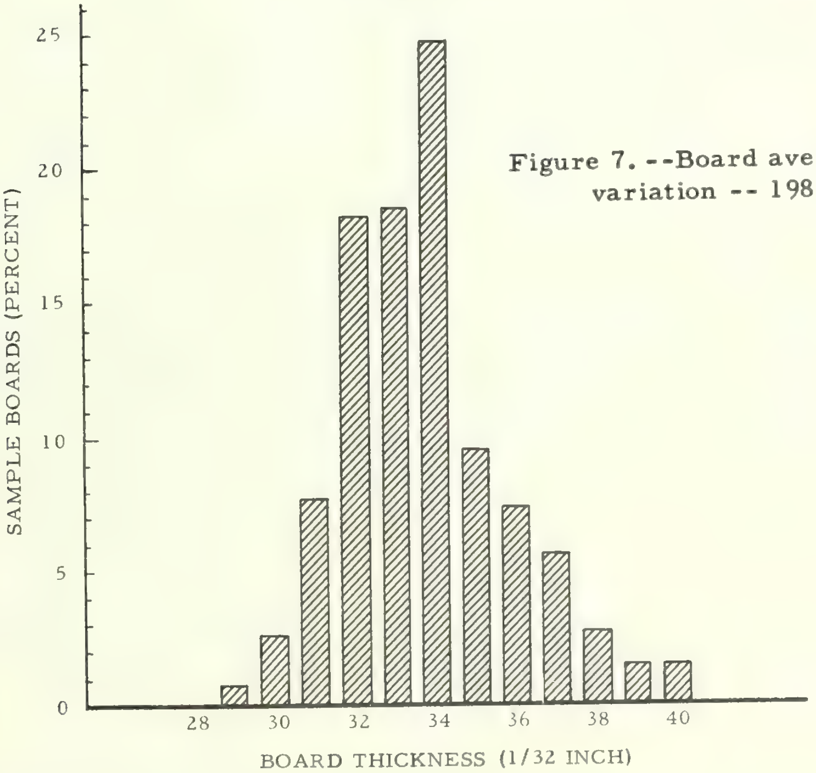


Figure 7. --Board average thickness variation -- 198 boards.

SUMMARY

Engelmann spruce is the most important single sawtimber species in Colorado. It contributes over 50 percent of the annual sawtimber supply.

To develop more reliable data for Engelmann spruce sawtimber appraisal, lumber grade recovery was studied at the J. S. Weidman mill in Durango, Colorado. The specific objectives of the study were: (1) to determine the lumber grades and volumes currently being recovered from Engelmann spruce sawtimber, and (2) to test the feasibility of grading Engelmann spruce saw logs. In addition, variations in log sawing time and sawing accuracy were investigated.

A total of 675 saw logs from 7 to 27 inches in diameter, made up the study sample. Of these, 84 percent were scaled as sound or full-scale logs.

The study logs yielded a gross scale of 66, 040 board feet. Deductions for defect amounted to 4. 5 percent of gross scale, or 2, 970 board feet, which left a net scale of 63, 070 board feet. Heart rot, the most common defect encountered, accounted for 44 percent of total cull. Sweep and crook contributed 29 percent of the loss.

Rough lumber volume recovery totaled 73, 558. 8 board feet. Volume losses due to drying, surfacing, and end-trimming reduced total recovery to 67, 150. 4 board feet. Change-of-grade and volume-loss factors were developed from a sample of 33, 073 board feet of lumber.

Log size and overrun were significantly correlated, with overrun greatest in the smaller diameter classes. Partial-scale logs yielded consistently higher overruns than did full-scale logs of comparable size.

Common lumber grades 1-2 and 3 contained over 70 percent of total dry surfaced lumber recovery. Select grades accounted for 3 percent of the lumber recovered; the remaining 27 percent was in low-common and dimension grades. Select-grade recovery improved as log diameter increased.

All study logs were graded in accordance with a modification of the trial log grades developed for associated species in the Pacific Northwest region. Both log grading and straight diameter classification accomplished some quality separation, although log grading accomplished very little for logs smaller than 14 inches in diameter. Minimum diameter specifications limit grading possibilities in these size classes. In the larger diameter classes, where the full range of log grades is applicable, logs can be separated as to quality by means of the log grade system. To the extent that quality separation is achieved, log grading appears to warrant further consideration.

Headsaw time required per unit of lumber produced varied inversely with log diameter. Study data indicated that lumber produced from 7-inch logs required approximately twice as much headsaw time per M b. m. as did lumber produced from 24-inch logs.

A sample of the study lumber was measured to determine dimensional variation. Board thickness averaged 34/32 inches, and ranged from 29/32 to 40/32 inches. Ninety-four percent of the lumber sampled fell within a 1/4 inch spread, from 31/32 to 38/32 inches.

APPENDIX

Trial log grades developed for associated species in the Pacific Northwest Region,[7] June 21, 1955.

Grade 1	Minimum diameter 20 inches Minimum length 12 feet 16-foot logs shall be 75 percent surface clear (3 clear faces or 12 feet of length) 14-foot logs shall have 12 feet of clear length 12-foot logs shall be 100 percent surface clear 2 pin knots allowed on clear portion of 16-foot logs that have 3 clear faces
Grade 2	Minimum diameter 16 inches, minimum length 12 feet Shall have two clear faces with one pin knot allowed on one clear face
Grade 3	Minimum diameter 12 inches, minimum length 12 feet May have knots in proportion to size of logs as follows: 12-inch logs, 2-inch live, 1-inch dead 18-inch logs, 3-inch live, 1-1/2-inch dead 24-inch logs, 4-inch live, 2-inch dead 30-inch logs, 5-inch live, 2-1/2-inch dead One knot over maximum size permitted
Grade 4	Minimum diameter 6 inches, minimum length 8 feet. Shall include logs not considered merchantable in the above classes
Knot clusters	Knot clusters other than the sap knot type (adventitious buds) shall be treated the same as a single knot of the same size as the cluster. Sap knot clusters shall be treated the same as the largest limb or knot in the cluster

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[7] The trial log grades were applied as written, with these exceptions: minimum diameter limits were reduced to 16 inches in grade 1, 14 inches in grade 2, and 10 inches in grade 3; 10-inch grade 3 logs may have 1-3/4-inch live, 3/4-inch dead knots.

Table 10.--Average net scale, lumber recovery, and log values for log grades 1-4, 16-foot logs

Log diameter (inches)	Full-scale logs				Partial-scale logs				All logs			
	Logs	Net Scribner scale	Dry surfaced recovery	Log value	Logs	Net Scribner scale	Dry surfaced recovery	Log value	Logs	Net Scribner scale	Dry surfaced recovery	Log value
	No.	Board feet		Dollars	No.	Board feet		Dollars	No.	Board feet		Dollars
					LOG GRADE 1[1]							
17	1	180	164.0	13.56	--	--	--	--	1	180	164.0	13.56
21	1	300	320.0	29.31	--	--	--	--	1	300	320.0	29.31
24	-	--	--	--	1	390	372.0	41.38	1	390	372.0	41.38
					LOG GRADE 2[2]							
14	2	110	141.4	12.24	--	--	--	--	2	110	134.3	11.99
15	9	140	154.7	12.70	2	110	131.1	12.48	11	135	148.5	12.52
16	3	160	170.8	13.60	5	135	152.7	13.06	8	143	165.1	13.42
17	2	180	189.7	14.94	4	153	174.6	13.95	6	161	184.0	14.67
18	5	210	211.4	16.72	2	165	197.1	15.17	7	197	205.1	16.29
19	2	240	235.8	18.94	2	170	219.9	16.71	4	205	228.6	18.26
20	3	280	263.1	21.60	--	—	--	--	3	280	254.5	20.60
21	2	300	293.1	24.70	--	--	--	--	2	300	282.6	23.29
22	1	330	326.0	28.24	1	270	291.1	23.24	2	300	313.1	26.35
23	1	380	361.6	32.22	1	300	315.8	26.06	2	340	345.8	29.76
					LOG GRADE 3[2]							
10	5	60	61.0	4.94	2	35	38.1	2.55	7	53	52.2	3.91
11	22	70	75.0	5.93	5	46	59.9	4.46	27	65	70.3	5.40
12	48	80	90.2	7.01	5	62	81.3	6.27	53	78	88.6	6.87
13	53	100	106.5	8.20	5	80	102.3	7.99	58	98	107.0	8.31
14	42	110	124.0	9.50	5	90	122.8	9.61	47	108	125.6	9.73
15	28	140	142.8	10.89	5	108	142.8	11.13	33	135	144.4	11.12
16	25	160	162.7	12.39	6	140	162.4	12.56	31	156	163.3	12.50
17	9	180	183.8	13.99	5	162	181.6	13.89	14	174	182.4	13.85
18	9	210	206.1	15.70	5	164	200.2	15.12	14	194	201.6	15.18
19	4	240	229.6	17.50	3	193	218.5	16.25	7	220	221.0	16.48
20	2	280	254.3	19.41	3	237	236.2	17.29	5	254	240.5	17.76
21	2	300	280.1	21.42	1	260	253.5	18.23	3	287	260.2	19.02
22	--	--	--	--	2	210	270.4	19.08	2	210	280.1	20.26
23	1	380	335.5	25.76	--	--	286.8	19.82	1	380	300.1	21.47
27	--	--	--	--	1	500	347.9	21.84	1	500	381.8	26.10
					LOG GRADE 4[2]							
7	19	30	27.2	1.99	2	15	27.0	1.96	21	29	27.7	2.04
8	50	30	35.9	2.68	1	20	33.3	2.43	51	30	35.8	2.67
9	56	40	45.7	3.45	2	30	41.8	3.04	58	40	45.2	3.40
10	48	60	56.8	4.30	9	42	52.5	3.81	57	57	56.1	4.21
11	37	70	69.0	5.22	12	56	65.3	4.74	49	67	68.3	5.12
12	6	80	82.4	6.21	7	64	80.3	5.81	13	72	81.9	6.12
13	7	100	97.0	7.29	1	90	97.4	7.04	8	99	97.0	7.21
14	4	110	112.8	8.42	1	80	116.7	8.42	5	104	113.4	8.39
15	3	140	129.7	9.64	—	--	—	--	3	140	131.1	9.67
16	1	160	147.9	10.93	--	--	—	--	1	160	150.3	11.03
17	--	--	--	--	1	160	187.6	13.48	1	160	170.9	12.49
19	1	240	209.4	15.26	--	--	--	--	1	240	216.1	15.68

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[1] Due to the extremely small sample of grade 1 logs, regression estimates of lumber recovery and log value were not computed. Lumber recovery and log value were computed directly from raw data.

[2] Dry surfaced volume recovery and log value are predicted values computed from **regressions**.

Table 11. --Percentage lumber grade recovery, dry finished basis -- log grade 1[1]

Log diameter (inches)	Logs	Select			Common				Dimension	Value per M b. m.
		B and better	C	D	1-2	3	4	5		
	No.	Percent								Dollars
					FULL-SCALE LOGS					
17	1	8.1	1.6	2.6	13.9	43.0	28.6	2.2	0	82.68
21	1	11.3	2.3	3.6	32.6	39.7	9.5	1.0	0	91.59
					PARTIAL-SCALE LOGS					
24	1	30.4	6.1	9.7	16.3	18.8	10.7	2.2	5.8	111.24
					ALL LOGS					
17	1	8.1	1.6	2.6	13.9	43.0	28.6	2.2	0	82.68
21	1	11.3	2.3	3.6	32.6	39.7	9.5	1.0	0	91.59
24	1	30.4	6.1	9.7	16.3	18.8	10.7	2.2	5.8	111.24

[1] All grade 1 study logs were 16 feet in length.

Table 12. --Percentage lumber grade recovery, dry finished basis -- log grade 2[1]

Log diameter (inches)	Logs	Select			Common				Dimension	Value[2] per M b.m.
		B and better	C	D	1-2	3	4	5		
	No.	Percent								Dollars
					FULL-SCALE LOGS					
14	2	2.9	0.6	0.9	35.8	46.9	12.2	0.7	0	86.54
15	9	4.5	.9	1.5	23.4	51.0	16.7	1.1	0.9	82.09
16	3	9.4	1.9	3.0	29.4	43.5	11.8	1.0	0	79.63
17	2	3.0	.6	1.0	9.4	61.8	22.8	1.4	0	78.77
18	5	3.8	.8	1.2	19.0	53.1	19.9	1.3	1.0	79.12
19	2	2.9	.6	.9	35.0	48.5	11.5	.6	0	80.32
20	3	7.0	1.4	2.2	19.4	51.3	17.4	1.3	0	82.11
21	2	1.3	.3	.4	22.1	49.5	24.9	1.5	0	84.27
22	1	11.0	2.2	3.5	13.7	43.6	24.0	2.0	0	86.64
23	1	15.8	3.2	5.1	18.9	34.5	15.3	1.7	5.5	89.10
					PARTIAL-SCALE LOGS					
15	2	14.2	2.9	4.6	31.6	31.8	13.4	1.5	0	95.19
16	5	4.7	.9	1.5	21.9	43.7	25.1	2.2	0	85.53
17	4	9.9	2.0	3.2	27.7	43.0	13.0	1.2	0	79.89
18	2	4.5	.9	1.4	11.0	36.5	39.8	5.9	0	76.98
19	2	1.8	.4	.6	9.1	35.1	44.2	6.4	2.4	75.97
22	1	0	0	0	12.1	50.5	31.8	1.9	3.7	79.84
23	1	12.8	2.6	4.1	5.2	33.0	24.1	2.2	16.0	82.54
					ALL LOGS					
14	2	2.9	0.6	0.9	35.8	46.9	12.2	0.7	0	89.25
15	11	6.1	1.2	2.0	24.8	47.9	16.1	1.1	0.8	84.31
16	8	6.7	1.3	2.1	25.0	43.6	19.6	1.7	0	81.28
17	6	7.6	1.5	2.4	21.6	49.4	16.3	1.2	0	79.77
18	7	4.0	.8	1.3	16.8	48.8	25.1	2.5	.7	79.40
19	4	2.4	.5	.8	23.0	42.2	26.7	3.3	1.1	79.88
20	3	7.0	1.4	2.2	19.4	51.3	17.4	1.3	0	80.95
21	2	1.3	.3	.4	22.1	49.5	24.9	1.5	0	82.42
22	2	5.8	1.2	1.9	12.9	46.7	27.7	2.0	1.8	84.15
23	2	14.5	2.9	4.6	12.8	33.8	19.3	1.9	10.2	86.05

[1] All grade 2 study logs were 16 feet in length.

[2] Value per M b.m. is based upon predicted average log volume recovery and log value, computed from regressions.

Table 13.--Percentage lumber grade recovery, dry finished basis -- log grade 3

Log diameter (inches)	Logs	Select			Common				Dimension	Value[1] per M b. m.
		B and better	C	D	1-2	3	4	5		
	No.	Percent								Dollars
16-foot logs:				FULL-SCALE LOGS						
10	5	1.2	0.2	0.4	26.7	48.6	20.8	2.1	0	80.93
11	22	.7	.1	.2	32.9	48.3	16.6	1.2	0	79.00
12	48	1.2	.3	.4	29.3	49.8	17.8	1.0	.2	77.78
13	53	.9	.2	.3	26.7	50.5	19.9	1.4	.1	77.02
14	42	.9	.2	.3	23.3	54.7	19.3	1.3	0	76.56
15	28	1.8	.4	.6	21.4	51.2	23.0	1.6	0	76.29
16	25	1.2	.2	.4	18.8	52.8	24.8	1.8	0	76.16
17	9	1.9	.4	.6	20.2	53.7	21.1	1.5	.6	76.13
18	9	1.0	.2	.3	19.8	46.7	25.8	5.2	1.0	76.16
19	4	0	0	0	13.8	61.0	21.8	1.2	2.2	76.23
20	2	3.5	.7	1.1	28.1	52.9	13.0	.7	0	76.34
21	2	3.1	.6	1.0	25.6	53.1	15.7	.9	0	76.47
23	1	1.5	.3	.5	13.9	38.0	37.2	2.5	6.1	76.78
Shorter logs:										
11	6	2.1	.4	.7	24.3	54.3	17.2	1.0	0	76.42
12	4	0	0	0	17.6	61.7	19.7	1.0	0	76.03
13	3	0	0	0	20.4	42.0	35.3	2.3	0	75.53
14	2	0	0	0	19.3	55.8	23.6	1.3	0	74.93
15	1	0	0	0	41.1	48.4	10.1	.4	0	74.23
16	1	0	0	0	31.3	35.2	31.5	2.0	0	73.57
17	2	.9	.2	.3	11.7	48.3	24.6	12.3	1.7	72.43
16-foot logs:				PARTIAL-SCALE LOGS						
10	2	0	0	0	25.5	50.0	23.1	1.4	0	66.96
11	5	0	0	0	18.6	41.2	37.8	2.4	0	74.42
12	5	0	0	0	18.2	45.2	34.4	2.2	0	77.13
13	5	4.0	.8	1.3	21.8	47.9	22.7	1.5	0	78.11
14	5	0	0	0	21.5	55.7	21.6	1.2	0	78.26
15	5	5.9	1.2	1.9	23.3	44.2	19.7	3.8	0	77.94
16	6	3.0	.6	1.0	19.9	46.5	27.2	1.8	0	77.32
17	5	4.3	.9	1.4	17.5	45.1	27.0	2.8	1.0	76.49
18	5	.4	.1	.1	14.2	43.2	35.8	4.0	2.2	75.50
19	3	3.9	.8	1.2	13.3	38.2	37.5	2.7	2.4	74.40
20	3	.7	.2	.2	9.7	36.8	41.1	8.9	2.4	73.20
21	1	0	0	0	26.3	52.0	20.6	1.1	0	71.91
22	2	1.1	.2	.4	1.8	15.2	72.5	7.5	1.3	70.55
27	1	0	0	0	.2	7.1	76.5	16.2	0	62.78
Shorter logs:										
16	1	0	0	0	14.8	43.1	39.5	2.6	0	72.33
16-foot logs:					ALL LOGS					
10	7	.9	.2	.3	26.4	49.0	21.3	1.9	0	74.93
11	27	.6	.1	.2	30.5	47.1	20.1	1.4	0	76.79
12	53	1.1	.2	.4	28.4	49.5	19.1	1.1	.2	77.49
13	58	1.2	.2	.4	26.3	50.3	20.1	1.4	.1	77.62
14	47	.8	.2	.2	23.1	54.8	19.6	1.3	0	77.43
15	33	2.4	.5	.8	21.7	50.1	22.5	2.0	0	77.05
16	31	1.5	.3	.5	19.0	51.7	25.2	1.8	0	76.54
17	14	2.7	.5	.9	19.3	50.9	23.1	1.9	.7	75.94
18	14	.8	.2	.3	17.8	45.4	29.3	4.8	1.4	75.29
19	7	1.7	.3	.6	13.6	50.9	28.8	1.8	2.3	74.59
20	5	1.9	.4	.6	17.3	43.5	29.4	5.5	1.4	73.85
21	3	2.1	.4	.7	25.8	52.8	17.3	.9	0	73.10
22	2	1.1	.2	.4	1.8	15.2	72.5	7.5	1.3	72.33
23	1	1.5	.3	.5	13.9	38.0	37.2	2.5	6.1	71.55
27	1	0	0	0	.2	7.1	76.5	16.2	0	68.36
Shorter logs:										
11	6	2.1	.4	.7	24.3	54.3	17.2	1.0	0	76.42
12	4	0	0	0	17.6	61.7	19.7	1.0	0	76.03
13	3	0	0	0	20.4	42.0	35.3	2.3	0	75.53
14	2	0	0	0	19.3	55.8	23.6	1.3	0	74.93
15	1	0	0	0	41.1	48.4	10.1	.4	0	74.23
16	2	0	0	0	22.8	39.3	35.6	2.3	0	73.40
17	2	.9	.2	.3	11.7	48.3	24.6	12.3	1.7	72.43

---

[1] Value per M b. m is based upon predicted average log volume recovery and log value, computed from regressions.

Table 14. --Percentage lumber grade recovery, dry finished basis -- log grade 4

Log diameter (inches)	Logs	Select			Common				Dimension	Value[1] per M b.m.
		B and better	C	D	1-2	3	4	5		
	No.	Percent								Dollars
		FULL-SCALE LOGS								
16-foot logs:										
7	19	0	0	0	10.7	43.1	18.7	4.0	23.5	73.12
8	50	.3	.1	.1	18.1	49.7	28.3	2.4	1.0	74.80
9	56	.5	.1	.2	20.5	53.5	22.9	1.9	.4	75.50
10	48	.1	0	0	26.8	52.4	19.6	1.1	0	75.69
11	37	1.7	.3	.5	20.4	53.4	21.9	1.8	0	75.60
12	6	1.0	.2	.3	26.6	54.2	16.8	.9	0	75.36
13	7	.3	.1	.1	9.1	54.6	32.7	3.1	0	75.03
14	4	.8	.2	.3	6.7	63.1	27.3	1.6	0	74.68
15	3	0	0	0	21.6	54.9	22.3	1.2	0	74.30
16	1	0	0	0	25.5	58.5	15.3	.7	0	73.93
19	1	0	0	0	15.7	49.4	27.2	1.6	6.1	72.87
Shorter logs:										
7	1	0	0	0	0	8.8	85.3	5.9	0	72.48
8	9	0	0	0	7.2	48.2	35.4	2.2	7.0	72.91
9	7	0	0	0	13.8	59.0	22.8	1.3	3.1	73.41
10	7	0	0	0	10.6	60.8	23.6	1.3	3.7	73.93
11	3	7.3	1.5	2.3	20.2	48.4	18.8	1.5	0	74.43
12	3	0	0	0	18.5	59.1	21.3	1.1	0	74.91
13	2	0	0	0	8.0	60.7	29.5	1.8	0	75.36
16	1	0	0	0	7.7	72.8	18.6	.9	0	75.79
18	1	4.8	1.0	1.5	15.9	60.4	15.4	1.0	0	76.19
		PARTIAL-SCALE LOGS								
16-foot logs:										
7	2	0	0	0	3.8	36.3	21.9	1.5	36.5	72.53
8	1	0	0	0	2.8	31.1	61.9	4.2	0	72.73
9	2	0	0	0	5.4	52.5	39.6	2.5	0	72.75
10	9	.3	.1	.1	16.6	50.4	30.6	1.9	0	72.67
11	12	.6	.1	.2	14.5	37.8	42.1	4.7	0	72.55
12	7	0	0	0	12.7	43.5	37.6	4.4	1.8	72.42
13	1	0	0	0	14.6	49.8	33.5	2.1	0	72.29
14	1	2.0	.4	.7	13.8	24.2	41.9	3.0	14.0	72.17
17	1	0	0	0	8.5	56.2	33.3	2.0	0	71.87
		ALL LOGS								
16-foot logs:										
7	21	0	0	0	10.1	42.5	19.0	3.8	24.6	73.75
8	51	.3	.1	.1	17.9	49.5	28.7	2.4	1.0	74.77
9	58	.5	.1	.2	20.0	53.4	23.5	1.9	.4	75.13
10	57	.1	0	.1	25.1	52.1	21.4	1.2	0	75.14
11	49	1.4	.3	.5	19.1	49.9	26.4	2.4	0	74.95
12	13	.5	.1	.2	19.1	48.4	27.9	2.8	1.0	74.68
13	8	.2	.1	.1	9.9	54.0	32.8	2.9	0	74.36
14	5	1.0	.2	.3	7.9	56.8	29.7	1.8	2.3	74.03
15	3	0	0	0	21.6	54.9	22.3	1.2	0	73.70
16	1	0	0	0	25.5	58.5	15.3	.7	0	73.39
17	1	0	0	0	8.5	56.2	33.3	2.0	0	73.08
19	1	0	0	0	15.7	49.4	27.2	1.6	6.1	72.53
Shorter logs:										
7	1	0	0	0	0	8.8	85.3	5.9	0	72.48
8	9	0	0	0	7.2	48.2	35.4	2.2	7.0	72.91
9	7	0	0	0	13.8	59.0	22.8	1.3	3.1	73.41
10	7	0	0	0	10.6	60.8	23.6	1.3	3.7	73.93
11	3	7.3	1.5	2.3	20.2	48.4	18.8	1.5	0	74.43
12	3	0	0	0	18.5	59.1	21.3	1.1	0	74.91
13	2	0	0	0	8.0	60.7	29.5	1.8	0	75.36
16	1	0	0	0	7.7	72.8	18.6	.9	0	75.79
18	1	4.8	1.0	1.5	15.9	60.4	15.4	1.0	0	76.19

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[1] Value per M b.m. is based upon predicted average log volume recovery and log value, computed from regressions.

Agriculture --- CSU, Ft. Collins

Mueller, Lincoln A., and Barger, Roland L.
1963. Lumber grade recovery from Engelmann spruce in Colorado.
Rocky Mountain Forest and Range Expt. Sta., Fort Collins,
Colo. 23 pp., illus. (U. S. Forest Serv. Res. Paper RM-1)

Engelmann spruce accounts for over half the annual sawtimber cut in Colorado. Specific objectives of this study were (1) determine lumber grades and volumes currently being recovered, (2) test feasibility of grading saw logs. Variations in sawing time and accuracy were also investigated. Dry surfaced lumber was recovered as follows: selects, 3 percent; grades 3 and better, 70 percent; 4 and 5, 26 percent, dimension, about 1 percent. Study logs were graded by a modification of trial log grades developed for associated species in the Pacific Northwest. The grading system appeared to be most effective for logs in the larger diameters.

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ril 1963

U. S. Forest Service
Research Paper [illegible]

Volume, Taper, and Related Tables for Southwestern Ponderosa Pine

by

Clifford A. Myers

ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION
RAYMOND PRICE, DIRECTOR FORT COLLINS, COLORADO
FOREST SERVICE U. S. DEPARTMENT OF AGRICULTURE

U. S. Forest Service Research Paper RM-2 May 1963

VOLUME, TAPER, AND RELATED TABLES
FOR
SOUTHWESTERN PONDEROSA PINE

by

Clifford A. Myers, Research Forester

Rocky Mountain Forest and Range Experiment Station[1]

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[1] Central headquarters maintained in cooperation with Colorado State University at Fort Collins.

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VOLUME, TAPER, AND RELATED TABLES FOR SOUTHWESTERN PONDEROSA PINE

by

Clifford A. Myers

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INTRODUCTION

The tables presented here give the basic mensurational values needed to measure ponderosa pines (Pinus ponderosa Laws.) in Arizona and New Mexico. They provide timber cruisers and growth estimators with the following:

1. Volumes in cubic feet to various limits of utilization.
2. Volumes in board feet, International 1/4-inch and Scribner log rules.
3. Scaling diameters of each log in trees of various diameter and merchantable height classes.
4. Distribution of board-foot volume among the logs of a tree.
5. Volumes of merchantable top wood as percentages of merchantable cubic feet to a 4.0-inch top.

Sample trees were measured in all areas of commercial ponderosa pine in Arizona and New Mexico.[2] Standards conformed to the needs of Forest Survey and the National Forests of the Southwestern Region.

Separate volume and taper tables were prepared for blackjack and old-growth ponderosa pines. Blackjacks and old-growth pines of equal diameter and height differ in taper and volume.[3] Blackjack pines are immature or young mature trees with dark bark and relatively rapid taper. Old-growth pines have yellowish bark, often in broad, flat plates, and less taper than blackjacks. Trees in these two groups have been tallied separately in cruising and other measurement work in the Southwest for many years.

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[2] Field measurements were made by personnel of the Southwestern Region, U. S. Forest Service, under the direction of Mr. Frank Bell.

[3] Hornibrook, Ezra M. Scribner volume tables for cut-over stands of ponderosa pine in Arizona. Jour. Agr. Res. 52: 961-974. 1936.

DEFINITIONS AND STANDARDS

Definitions of variables used in the tables, and of standards followed in field measurement and computations are as follows:

Diameter breast high (d. b. h.). --Measured to 0.1 inch outside bark 4.5 feet above ground level at the uphill side of the tree. Full-inch diameter classes, with class midpoints at the half-inch marks, were used in the tables (12.5, 13.5, etc.).

Scaling diameter of logs. --Average diameter inside bark to 0.1 inch, measured at the upper (small) end of logs or half-logs. Saw log diameter classes followed conventional scaling practice with the class midpoints at even inches (8.0, 9.0, etc.).

Minimum top diameter of sawtimber trees. --Diameter inside bark that represents average full saw log utilization of Southwestern ponderosa pine. Logs with a scaling diameter less than 7.6 inches (8-inch class) were not included in saw log volume, which conforms to the practice in most of Arizona and New Mexico. The average minimum top diameters, inside bark, used in computing tree volumes were:

Tree d. b. h. (Inches)	Minimum top saw log diameter (Inches)
12-13	8
14-21	9
22-26	10
27-31	11
32-35	12
36-39	13
40-42	14
43-45	15
46-47	16

Total height.--Measured from ground level at the uphill side of the tree upward to the tip. Forked, stag-topped, or other deformed trees were not included in the sample. Midpoints of the total height classes used in the tables were multiples of 10.0 feet.

Height in logs.--Measured from the top of a stump 1.0 foot high upward to the limit of saw log utilization. Each tree was divided into as many standard 16.5-foot-long logs as possible. An additional half-log, if present, was taken from the uppermost part of the merchantable length. Portions of the bole above the height of minimum top saw log diameter were included in the uppermost saw log if the standard length of the log or half-log ended within 4.0 feet above this height. This was done to avoid biased negative error in volumes[4] and positive error in top diameter averages.

EXPLANATION OF TABLES

The general definitions and standards given apply to all tables. Explanation of each type of table and suggestions for use are presented here.

VOLUME TABLES

Headings and footnotes with each volume table (tables 1a-8b) give the volume unit, type of height measurement, and utilization standards used in its compilation. Ten-foot or half-log height classes and full-inch diameter classes were used in all tables.

---

[4] Chapman, Herman H., and Meyer, Walter H. Rules for measuring standard merchantable heights, p. 92. In Forest Mensuration. 522 pp., illus. New York: McGraw-Hill Book Co. 1950.

The volume tables were derived from linear regressions in V and D^2H, given in the footnotes, of the form:

$$V = a + b\ D^2H, \text{ where:}$$

V = gross volume in the appropriate unit
D = diameter breast high outside bark
H = total height in feet or merchantable height in logs
a, b = regression constants

Equations for cubic volumes of sawtimber trees, with heights in feet, apply over the full range of the basic data. Other equations correctly expressed the relationship between volume and D^2H except for the smallest trees or the lowest values of D^2H. Tabular volumes for values of D^2H below the limits given with these equations were determined directly from the basic data as separate linear relationships.

The number of logs in a tree shown in the tables is not necessarily the number that will actually be cut from it. Instead, it is the number of logs between the stump and the height where minimum top diameter is reached. To locate the minimum top, the "4-foot rule" explained on page 2 should be used.

Volume of nonmerchantable logs below the height of minimum top diameter should be deducted according to the percentages in table 10, not by tallying fewer logs in the tree. For example, assume that a sound blackjack 30 inches in diameter has a bole length of 82.5 feet (5 logs) between the stump and the height where diameter inside bark is 11 inches. The tree has a gross volume of 1,344 board feet Scribner rule (table 6a). The top log is too limby to send to the sawmill. This log contains 4 percent of the board feet in the tree (table 10) and the other logs contain 96 percent. When 4 percent or 54 board feet is deducted, the tree contains 1,290 board feet. If the tree were tallied as a 30-inch, 4-log tree, it would be incorrectly credited with a volume of 1,065 board feet.

SCALING DIAMETERS OF LOGS IN A TREE

Tabulated scaling diameters (tables 9a, 9b) represent average tapers for the sample of trees measured. The range of tree diameters and heights is less than for the volume tables because too few trees were measured in some height and diameter classes to insure reliable averages.

Tree volumes obtained by summing the volumes of logs with the indicated scaling diameters will not equal tree volumes in the volume tables. Taper tables are constructed by averaging diameters at the taper points, while volume tables are based on averages of tree volumes. Tree volumes computed from the taper tables will usually differ from volume table values by less than 10 percent, however.

Top logs in the taper tables do not always have the minimum top scaling diameter appropriate for the size of tree. That is because the saw log trees were not utilized to a fixed top diameter, but in lengths that were multiples of 8.25 feet. For example, scaling diameters of top logs or half-logs of 20-inch blackjacks (table 9a) range from 9 inches (4.5-log trees) to 11 inches (2-log trees). However, most sample trees 20 inches in diameter were utilized to a 9-inch top.

Despite these limitations, taper tables are useful tools for tree measurement. One use is for estimating volume by log-quality classes. The logs of a tree usually differ in grade, but this difference cannot be shown by the values in a volume table. If the scaling diameter and grade of each log of a tree is known, volumes in each log-quality class can be determined.

PERCENTAGE OF TREE BOARD-FOOT VOLUME IN EACH LOG

The board-foot volume in each log-quality class can also be determined with the percentages from table 10. Each line in the body of the table gives the distribution of volume among the logs of a tree of specified diameter and merchantable length. In 30-inch, 3-log trees, the butt log contains 57 percent of the board feet, the middle log contains 32 percent, and the top log 11 percent. A 30-inch, 3-log blackjack contains 785 board feet Scribner rule (table 6a). The volume of each log, from the butt upwards, is 448, 251, and 86 board feet. These amounts can be assigned to the proper log-quality classes.

An important use of table 10 has already been explained in the description of the volume tables. Nonmerchantable logs below the height of minimum top diameter should be deducted from tree volume by means of the percentages shown, not by tallying fewer logs in the tree.

The percentages in table 10 can be used for both old-growth and blackjack ponderosa pines, and with both the Scribner and International 1/4-inch log rules. Percentages for diameters that are not included can be obtained by interpolation.

CONVERSION FACTORS FOR VOLUME OF MERCHANTABLE TOPS

Wood 4.0 inches in diameter or larger inside bark that is not harvested for saw logs is often suitable for pulpwood. Top wood volumes can be computed directly by means of the appropriate volume tables (tables 2a, 4a; 2b, 4b) but it is sometimes more convenient to obtain them by converting other measures of volume.

The conversion factors (table 11) were obtained by determining for each tree the percent volume of sapwood from the formula:

$$\frac{\text{Volume from upper limit of utilization for saw logs to 4.0 inches d.i.b.}}{\text{Merchantable cubic-foot volume, stump to 4.0-inch top}} \times 100$$

The resulting percentages were then smoothed graphically.

Each conversion factor is the average percentage of merchantable cubic-foot volume (tables 2a, 2b, 3a, 3b) left in the tops after saw log harvest. For example, a stand containing 1,000 merchantable cubic feet of wood in old-growth trees 13.0 to 14.9 inches diameter has 1000 × 0.191 or 191 cubic feet of usable top wood.

Table 1a. --Volumes of entire stem in cubic feet, blackjack ponderosa pines
Arizona and New Mexico

Cubic feet inside bark
Entire stem including stump and top

Total height above ground

Diameter breast height outside bark (Inches)	Total height in feet													Basis: Trees
	20	30	40	50	60	70	80	90	100	110	120	130	140	
	Volume in cubic feet													No.
5	1.69	2.24	2.79	3.35										10
6	2.13	2.90	3.67	4.44	5.21									20
7	2.64	3.67	4.69	5.72	6.74									11
8	3.22	4.54	5.86	7.18	8.49	9.81								12
9	3.88	5.53	7.17	8.82	10.5	12.2								19
10	4.61	6.62	8.63	10.6	12.8	15.1								14
11	5.41	7.82	10.2	12.8	15.6	18.4	21.2							22
12	6.29	9.14	12.1	15.3	18.6	21.9	25.2	28.5						34
13		10.6	14.2	18.1	21.9	25.7	29.6	33.4						33
14		12.2	16.6	21.0	25.4	29.9	34.3	38.7	43.1					32
15		14.1	19.1	24.2	29.2	34.3	39.3	44.4	49.4					33
16			21.8	27.5	33.3	39.0	44.7	50.4	56.2					32
17			24.7	31.1	37.6	44.0	50.4	56.9	63.3	69.8				41
18			27.7	34.9	42.1	49.3	56.5	63.7	70.9	78.1				36
19			30.9	38.9	46.9	54.9	62.9	70.9	78.9	86.9				30
20			34.3	43.1	51.9	60.8	69.6	78.4	87.3	96.1				34
21				47.5	57.2	67.0	76.7	86.4	96.1	106				26
22				52.1	62.8	73.4	84.1	94.7	105	116				37
23				57.0	68.6	80.2	91.8	103	115	127	138			26
24				62.0	74.6	87.3	99.9	113	125	138	150			32
25					81.0	94.6	108	122	136	149	163	177		24
26					87.5	102	117	132	147	161	176	191	206	30
27					94.3	110	126	142	158	174	190	206	222	23
28					101	118	136	153	170	187	204	221	238	27
29					109	127	145	164	182	200	219	237	255	19
30					116	136	155	175	195	214	234	253	273	24
31					124	145	166	187	208	228	249	270	291	18
32					132	154	177	199	221	243	265	288	310	18
33					141	164	188	211	235	259	282	306	329	15
34						174	199	224	249	274	299	324	349	21
35						184	211	237	264	290	317	343	370	15
36						195	223	251	279	307	335	363	391	22
37						206	235	265	295	324	354	383	413	9
38						217	248	279	311	342	373	404	435	4
39							261	294	327	360	393	425	458	4
40								309	344	378	413	447	482	3
41								325	361	397	434	470	506	2
42								341	379	417	455	493	531	0
43								357	397	437	476	516	556	1
Basis: No. trees	2	23	39	70	105	115	139	127	103	58	16	12	4	813

Block indicates extent of basic data.
Derived from: $V = 0.002103\ D^2H - 1.091458$ for D^2H larger than 6,000.
Standard error of estimate: ± 16.48 percent.
Diameter classes full-inch; e.g. 20-inch class includes 20.0 to 20.9.

Table 1b. --Volumes of entire stem in cubic feet, old-growth ponderosa pines
Arizona and New Mexico

Cubic feet inside bark
Entire stem including stump and top

Total height above ground

Diameter breast height outside bark (Inches)	Total height in feet											Basis: Trees
	40	50	60	70	80	90	100	110	120	130	140	
	Volume in cubic feet											No.
12	14.0	17.6	21.2	24.8	28.4	32.0	35.6					21
13	16.4	20.6	24.8	29.0	33.2	37.4	41.6					25
14	19.0	23.8	28.6	33.5	38.3	43.2	48.0					18
15	21.7	27.3	32.8	38.3	43.8	49.4	54.9					26
16	24.7	30.9	37.2	43.5	49.7	56.0	62.3					28
17	27.8	34.8	41.9	48.9	56.0	63.0	70.1	77.1				30
18	31.1	39.0	46.9	54.7	62.6	70.5	78.4	86.3				24
19	34.6	43.4	52.1	60.9	69.6	78.4	87.1	95.9	105			27
20		48.0	57.6	67.3	77.0	86.7	96.3	106	116	125		25
21		52.8	63.4	74.1	84.7	95.4	106	117	127	138		39
22		57.9	69.5	81.2	92.8	104	116	128	139	151		29
23		63.2	75.9	88.6	101	114	127	139	152	165		23
24			82.5	96.3	110	124	138	152	165	179		30
25			89.4	104	119	134	149	164	179	194		27
26			96.6	113	129	145	161	177	194	210		35
27			104	121	139	156	174	191	209	226		28
28			112	130	149	168	187	205	224	243	261	33
29			120	140	160	180	200	220	240	260	280	20
30			128	149	171	192	214	235	257	278	299	23
31			137	159	182	205	228	251	274	297	319	23
32				170	194	218	243	267	291	316	340	30
33				180	206	232	258	284	310	335	361	20
34				191	219	246	274	301	328	356	383	21
35				203	232	261	290	319	348	377	406	15
36				214	245	276	306	337	368	398	429	22
37				226	259	291	323	356	388	420	453	18
38				238	273	307	341	375	409	443	477	21
39				251	287	323	359	395	431	467	502	12
40					302	339	377	415	453	490	528	8
41					317	356	396	436	475	515	555	9
42						374	415	457	499	540	582	3
43						392	435	479	522	566	609	6
44						410	455	501	547	592	638	1
45						429	476	524	571	619	667	2
46						448	497	547	597	647	696	2
47							519	571	623	675	727	1
Basis: No. trees	8	33	53	94	120	126	123	103	44	19	2	725

Block indicates extent of basic data.
Derived from: $V = 0.002302\, D^2 H - 0.402357$.
Standard error of estimate: ± 11.44 percent.
Diameter classes full-inch; e. g. 20-inch class includes 20.0 to 20.9.

Table 2a. --Merchantable volumes in cubic feet to a 4.0-inch top, blackjack ponderosa pines
Arizona and New Mexico

Cubic feet inside bark
Merchantable stem excluding stump and top

Top diameter 4.0 inches inside bark
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Total height in feet													Basis:
	20	30	40	50	60	70	80	90	100	110	120	130	140	Trees
	Volume in cubic feet													No.
5	0.87	1.40	1.94	2.47										10
6	1.29	2.04	2.79	3.53	4.28									20
7	1.79	2.78	3.78	4.77	5.77									11
8	2.35	3.63	4.91	6.19	7.47	8.75								12
9	2.99	4.59	6.18	7.78	9.38	11.0								19
10	3.70	5.65	7.60	9.55	11.5	13.8								14
11	4.48	6.82	9.16	11.5	14.3	17.0	19.7							22
12	5.33	8.09	10.9	14.0	17.2	20.4	23.6	26.9						34
13		9.47	12.9	16.7	20.4	24.2	27.9	31.7						33
14		11.0	15.2	19.6	23.9	28.2	32.5	36.8	41.2					32
15		12.8	17.7	22.6	27.6	32.5	37.5	42.4	47.3					33
16			20.3	25.9	31.5	37.1	42.7	48.3	53.9					32
17			23.1	29.4	35.7	42.0	48.3	54.6	60.9	67.2				41
18			26.1	33.1	40.2	47.2	54.2	61.3	68.3	75.3				36
19			29.2	37.0	44.8	52.7	60.5	68.3	76.1	83.9				30
20			32.5	41.1	49.8	58.4	67.1	75.7	84.3	93.0				34
21				45.5	55.0	64.5	74.0	83.5	93.0	102				26
22				50.0	60.4	70.8	81.2	91.6	102	112				37
23				54.7	66.1	77.4	88.8	100	111	123	134			26
24				59.6	72.0	84.3	96.7	109	121	134	146			32
25					78.2	91.5	105	118	132	145	158	172		24
26					84.6	99.0	113	128	142	157	171	186	200	30
27					91.2	107	122	138	153	169	185	200	216	23
28					98.1	115	132	148	165	182	198	215	232	27
29					105	123	141	159	177	195	213	231	248	19
30					113	132	151	170	189	208	227	247	266	25
31					120	141	161	182	202	222	243	263	284	18
32					128	150	172	193	215	237	259	280	302	18
33					136	159	183	206	229	252	275	298	321	15
34						169	194	218	243	267	292	316	341	21
35						179	205	231	257	283	309	335	361	15
36						190	217	244	272	299	327	354	381	22
37						200	229	258	287	316	345	374	403	9
38						211	242	272	303	333	364	394	425	4
39							255	287	319	351	383	415	447	4
40								301	335	369	403	436	470	3
41								317	352	387	423	458	494	2
42								332	369	406	444	481	518	0
43								348	387	426	465	504	543	1
Basis: No. trees	2	23	39	70	105	115	139	127	103	58	16	12	4	813

Block indicates extent of basic data.
Derived from: $V = 0.002056\ D^2H - 2.061477$ for D^2H larger than 6,500.
Standard error of estimate: ± 14.81 percent.
Diameter classes full-inch; e. g. 20-inch class includes 20.0 to 20.9.

Table 2b. --Merchantable volumes in cubic feet to a 4.0-inch top, old-growth ponderosa pines
Arizona and New Mexico

Cubic feet inside bark
Merchantable stem excluding stump and top

Top diameter 4.0 inches inside bark
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Total height in feet											Basis: Trees
	40	50	60	70	80	90	100	110	120	130	140	
	Volume in cubic feet											No.
12	12.7	16.2	19.7	23.2	26.7	30.3	33.8					21
13	15.0	19.1	23.2	27.3	31.4	35.5	39.7					25
14	17.5	22.3	27.0	31.7	36.5	41.2	46.0					18
15	20.2	25.6	31.1	36.5	41.9	47.3	52.7					26
16	23.1	29.3	35.4	41.5	47.7	53.8	60.0					28
17	26.2	33.1	40.0	46.9	53.8	60.7	67.6	74.5				30
18	29.4	37.1	44.9	52.6	60.3	68.0	75.7	83.5				24
19	32.9	41.4	50.0	58.6	67.2	75.7	84.3	92.9	101			27
20		45.9	55.4	64.9	74.4	83.8	93.3	103	112	122		25
21		50.7	61.1	71.5	81.9	92.4	103	113	124	134		39
22		55.6	67.1	78.5	89.9	101	113	124	136	147		29
23		60.8	73.3	85.7	98.2	111	123	136	148	160		23
24			79.8	93.3	107	120	134	147	161	175		30
25			86.5	101	116	131	145	160	175	189		27
26			93.6	109	125	141	157	173	189	204		35
27			101	118	135	152	169	186	203	220		28
28			108	127	145	163	182	200	218	237	255	33
29			116	136	156	175	195	214	234	254	273	20
30			124	145	166	187	208	229	250	271	292	23
31			133	155	178	200	222	245	267	289	312	23
32				165	189	213	237	261	284	308	332	30
33				176	201	226	252	277	302	328	353	20
34				186	213	240	267	294	321	347	374	21
35				197	226	254	283	311	340	368	396	15
36				209	239	269	299	329	359	389	419	22
37				221	252	284	316	347	379	411	443	18
38				233	266	299	333	366	400	433	467	21
39				245	280	315	350	386	421	456	491	12
40					294	331	368	405	442	479	516	8
41					309	348	387	426	465	503	542	9
42						365	406	447	487	528	569	3
43						383	425	468	511	553	596	6
44						400	445	490	534	579	624	1
45						419	465	512	559	605	652	2
46						437	486	535	584	632	681	2
47							507	558	609	660	711	1
Basis: No. trees	8	33	53	94	120	126	123	103	44	19	2	725

Block indicates extent of basic data.
Derived from: $V = 0.002255 D^2 H - 1.440832$.
Standard error of estimate: ± 11.73 percent.
Diameter classes full-inch; e. g. 20-inch class includes 20.0 to 20.9.

Table 3a. --Merchantable volumes in cubic feet to a 4.0-inch top, blackjack ponderosa pines
Arizona and New Mexico

Cubic feet inside bark
Merchantable stem excluding stump and top

Top diameter 4.0 inches inside bark
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Number of merchantable 16-foot logs													Basis: Trees
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	
	Volume in cubic feet													No.
12	14.0	17.6	21.2	24.8	28.4									32
13	15.2	19.4	23.6	27.8	32.0	36.1								33
14	16.5	21.3	26.1	31.0	35.8	40.7								32
15	17.9	23.4	28.9	34.4	40.0	45.4	50.7							33
16	19.3	25.6	31.8	38.1	44.4	50.4	56.4	62.4						32
17	20.9	27.9	35.0	42.0	48.9	55.6	62.4	69.2						41
18		30.4	38.3	46.1	53.7	61.2	68.8	76.3	83.9					36
19		33.0	41.8	50.3	58.7	67.1	75.5	83.9	92.3					30
20		35.8	45.4	54.7	64.0	73.3	82.6	91.9	101					34
21		38.7	49.1	59.3	69.6	79.8	90.0	100	110					26
22		41.7	53.0	64.2	75.4	86.6	97.8	109	120					37
23		44.9	57.1	69.3	81.5	93.7	106	118	130	143				26
24		48.1	61.3	74.6	87.9	101	114	128	141	154				32
25			65.8	80.1	94.5	109	123	138	152	166	181			24
26				85.9	101	117	132	148	163	179	195	210		30
27				91.8	109	125	142	159	175	192	209	226		23
28				98.0	116	134	152	170	188	206	224	242		27
29				104	124	143	162	181	201	220	239	258	278	19
30				111	132	152	173	193	214	234	255	276	296	24
31				118	140	162	184	206	228	250	271	293	315	18
32				125	148	172	195	218	242	265	288	312	335	18
33				132	157	182	207	232	256	281	306	331	356	15
34				140	166	192	219	245	271	298	324	350	377	21
35				148	175	203	231	259	287	315	343	370	398	15
36					185	214	244	273	303	332	362	391	421	22
37					195	226	257	288	319	350	381	412	443	9
38					205	238	270	303	336	369	401	434	467	4
39						250	284	319	353	388	422	457	491	4
40							298	335	371	407	443	480	516	3
41							313	351	389	427	465	503	541	2
42							328	368	407	447	487	527	567	0
43							343	385	426	468	510	552	594	1
Basis: No. trees	21	43	77	93	92	117	87	78	55	17	18	4	1	703

Block indicates extent of basic data.
Derived from: V = 0.044204 D^2H + 8.266000 for D^2H larger than 800.
Standard error of estimate: ± 12.81 percent.
Diameter classes full-inch; e. g. 20-inch class includes 20.0 to 20.9.

Table 3b. --Merchantable volumes in cubic feet to a 4.0-inch top, old-growth ponderosa pines
Arizona and New Mexico

Cubic feet inside bark
Merchantable stem excluding stump and top

Top diameter 4.0 inches inside bark
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Number of merchantable 16-foot logs													Basis: Trees
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	
	Volume in cubic feet													No.
12	13.8	17.7	21.7	25.7	29.6	33.6								21
13	15.1	19.7	24.3	29.0	33.6	38.2	42.8							25
14	16.5	21.8	27.2	32.5	37.8	43.2	48.5							18
15	18.0	24.1	30.2	36.3	42.4	48.5	54.6	60.3						26
16	19.7	26.6	33.5	40.4	47.2	54.1	60.7	66.9						28
17	21.4	29.1	36.9	44.7	52.4	59.9	66.9	73.9						30
18		31.9	40.5	49.2	57.8	65.6	73.5	81.3	89.1					24
19		34.8	44.4	54.0	63.0	71.7	80.4	89.1	97.8	107				27
20		37.8	48.5	58.9	68.5	78.1	87.7	97.3	107	117	126			25
21		41.0	52.7	63.7	74.3	84.9	95.4	106	117	127	138	148		39
22			57.2	68.7	80.3	91.9	103	115	127	138	150	161		29
23				74.0	86.6	99.3	112	125	137	150	162	175		23
24				79.5	93.2	107	121	134	148	162	176	189		30
25				85.2	100	115	130	145	160	174	189	204		27
26				91.2	107	123	139	155	171	188	204	220		35
27				97.3	115	132	149	167	184	201	218	236		28
28				104	122	141	159	178	197	216	234	252		33
29				110	130	150	170	190	210	230	250	270		20
30				117	138	160	181	202	224	245	266	287	309	23
31				124	147	170	192	215	238	260	283	306	329	23
32				132	156	180	204	228	252	277	301	325	349	30
33					165	191	216	242	267	293	319	344	370	20
34					174	201	229	256	283	310	337	365	392	21
35					184	213	241	270	299	328	357	386	414	15
36					194	224	255	285	316	346	376	407	437	22
37					204	236	268	300	332	365	397	429	461	18
38						248	282	316	350	384	418	452	485	21
39						261	296	332	368	403	439	475	510	12
40						273	311	348	386	423	461	498	536	8
41						287	326	365	405	444	483	523	562	9
42							341	383	424	465	507	548	589	3
43							357	400	444	487	530	573	617	6
44							373	418	464	509	554	600	645	1
45							390	437	484	532	579	626	674	2
46							406	456	505	555	604	654	703	2
47								475	527	578	630	682	733	1
Basis: No. trees	10	27	46	62	72	87	129	107	95	62	22	6	0	725

Block indicates extent of basic data.
Derived from: $V = 0.045736\ D^2H + 10.857212$ for D^2H larger than 1,000.
Standard error of estimate: ± 13.13 percent.
Diameter classes full-inch; e. g. 20-inch class includes 20.0 to 20.9.

Table 4a. --Merchantable volumes in cubic feet to the variable top limit of saw log utilization, blackjack ponderosa pines

Arizona and New Mexico

Cubic feet inside bark
Merchantable stem excluding stump and top

Top diameter variable
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Total height in feet: 30	40	50	60	70	80	90	100	110	120	130	140	Basis: Trees
	Volume in cubic feet												No.
12	2.83	6.02	9.22	12.4	15.6	18.8	22.0						32
13	4.43	8.15	11.9	15.6	19.3	23.0	26.8						33
14	6.14	10.4	14.7	19.0	23.3	27.6	31.9	36.2					32
15	7.98	12.9	17.8	22.7	27.6	32.5	37.4	42.3					33
16		15.5	21.1	26.6	32.2	37.8	43.3	48.9					32
17		18.3	24.5	30.8	37.1	43.3	49.6	55.8	62.1				41
18		21.2	28.2	35.2	42.2	49.2	56.2	63.2	70.2				36
19		24.3	32.1	39.9	47.6	55.4	63.2	70.9	78.7				30
20			36.2	44.8	53.4	61.9	70.5	79.1	87.7				34
21			40.5	49.9	59.4	68.8	78.2	87.7	97.1				26
22			45.0	55.3	65.7	76.0	86.3	96.7	107				37
23			49.7	61.0	72.2	83.5	94.8	106	117	129			26
24			54.6	66.8	79.1	91.4	104	116	128	140			32
25				73.0	86.2	99.5	113	126	139	153	166		24
26				79.3	93.7	108	122	137	151	165	180	194	30
27				86.0	101	117	132	148	163	179	194	210	23
28				92.8	109	126	143	159	176	192	209	226	27
29				99.9	118	135	153	171	189	207	224	242	19
30				107	126	145	164	183	202	221	240	259	24
31				115	135	155	176	196	216	237	257	277	18
32				123	144	166	187	209	231	252	274	295	18
33				131	154	177	200	223	245	268	291	314	15
34					163	188	212	236	261	285	309	334	21
35					173	199	225	251	276	302	328	354	15
36					184	211	238	265	293	320	347	374	22
37					194	223	252	281	309	338	367	395	9
38					205	236	266	296	326	357	387	417	4
39						248	280	312	344	376	408	440	4
40							295	328	362	395	429	462	3
41							310	345	380	415	451	486	2
42							325	362	399	436	473	510	0
43							341	380	419	457	496	534	1
Basis: No. trees	1	7	38	88	110	139	127	103	58	16	12	4	703

Block indicates extent of basic data.
Derived from: $V = 0.002043 D^2 H - 6.744303$.
Standard error of estimate: ± 16.17 percent.
Diameter classes full-inch; e. g. 20-inch class includes 20.0 to 20.9.

Table 4b. --Merchantable volumes in cubic feet to the variable top limit of saw log utilization,
old-growth ponderosa pines
Arizona and New Mexico

Cubic feet inside bark
Merchantable stem excluding stump and top

Top diameter variable
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Total height in feet											Basis: Trees
	40	50	60	70	80	90	100	110	120	130	140	
	Volume in cubic feet											No.
12	8.75	12.2	15.7	19.2	22.7	26.1	29.6					21
13	11.1	15.1	19.2	23.2	27.3	31.4	35.4					25
14	13.6	18.2	22.9	27.6	32.3	37.0	41.6					18
15	16.2	21.6	26.9	32.3	37.6	43.0	48.3					26
16	19.1	25.1	31.2	37.3	43.3	49.4	55.4					28
17	22.1	28.9	35.7	42.6	49.4	56.2	63.0	69.8				30
18	25.3	32.9	40.5	48.2	55.8	63.4	71.0	78.6				24
19	28.7	37.2	45.6	54.1	62.6	71.0	79.5	87.9	96.4			27
20		41.6	51.0	60.3	69.7	79.0	88.4	97.7	107	116		25
21		46.3	56.6	66.9	77.2	87.4	97.7	108	118	129		39
22		51.2	62.5	73.7	85.0	96.3	108	119	130	141		29
23		56.3	68.6	80.9	93.2	105	118	130	142	155		23
24			75.0	88.4	102	115	128	142	155	169		30
25			81.7	96.2	111	125	140	154	169	183		27
26			88.6	104	120	136	151	167	182	198		35
27			95.8	113	130	146	163	180	197	214		28
28			103	121	139	158	176	194	212	230	248	33
29			111	130	150	169	189	208	227	247	266	20
30			119	140	160	181	202	223	243	264	285	23
31			127	149	172	194	216	238	260	282	304	23
32				159	183	206	230	253	277	300	324	30
33				170	195	220	245	270	295	320	345	20
34				180	207	233	260	286	313	339	366	21
35				191	219	247	275	303	331	360	388	15
36				202	232	262	291	321	351	380	410	22
37				214	245	277	308	339	370	402	433	18
38				226	259	292	325	358	391	424	457	21
39				238	273	307	342	377	412	446	481	12
40					287	323	360	396	433	469	506	8
41					302	340	378	417	455	493	532	9
42						357	397	437	477	518	558	3
43						374	416	458	500	542	585	6
44						392	436	480	524	568	612	1
45						410	456	502	548	594	640	2
46						428	476	524	572	621	669	2
47							497	547	598	648	698	1
Basis: No. trees	8	33	53	94	120	126	123	103	44	19	2	725

Block indicates extent of basic data.
Derived from: $V = 0.002226\ D^2H - 5.161622$.
Standard error of estimate: ± 12.34 percent.
Diameter classes full-inch; e. g. 20-inch class includes 20.0 to 20.9.

Table 5a. --Volumes in board-feet Scribner rule, blackjack ponderosa pines
Arizona and New Mexico

Board-feet inside bark
Merchantable stem excluding stump and top

Top diameter variable
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Total height in feet												Basis: Trees
	30	40	50	60	70	80	90	100	110	120	130	140	
	Volume in board-feet												No.
12	18	33	48	62	77	92	107						32
13	25	43	60	77	94	112	129						33
14	33	53	73	93	113	133	153	177					32
15	42	65	87	110	133	156	186	219					33
16		77	103	128	154	188	226	263					32
17		90	119	148	183	226	268	311	353				41
18		103	136	171	218	266	313	361	408				36
19		118	154	202	255	308	361	413	466				30
20			177	236	294	352	411	469	527				34
21			206	271	335	399	463	527	592				26
22			237	307	378	448	518	588	659				37
23			269	346	422	499	576	652	729	806			26
24			302	386	469	552	636	719	802	886			32
25				427	518	608	698	788	879	969	1,059		24
26				471	568	666	763	861	958	1,056	1,153	1,251	30
27				516	621	726	831	936	1,041	1,146	1,251	1,356	23
28				562	675	788	901	1,013	1,126	1,239	1,352	1,465	27
29				611	731	852	973	1,094	1,215	1,336	1,456	1,577	19
30				661	790	919	1,048	1,177	1,306	1,436	1,565	1,694	24
31				712	850	988	1,126	1,263	1,401	1,539	1,677	1,815	18
32				765	912	1,059	1,206	1,352	1,499	1,646	1,792	1,939	18
33				820	976	1,132	1,288	1,444	1,600	1,756	1,911	2,067	15
34					1,042	1,208	1,373	1,538	1,704	1,869	2,034	2,199	21
35					1,110	1,285	1,461	1,636	1,811	1,986	2,161	2,336	15
36					1,180	1,365	1,550	1,735	1,921	2,106	2,291	2,476	22
37					1,252	1,448	1,643	1,838	2,034	2,229	2,424	2,619	9
38					1,326	1,532	1,738	1,944	2,150	2,355	2,561	2,767	4
39						1,619	1,835	2,052	2,269	2,485	2,702	2,919	4
40							1,935	2,163	2,391	2,619	2,847	3,074	3
41							2,038	2,277	2,516	2,755	2,995	3,234	2
42							2,143	2,394	2,645	2,895	3,146	3,397	0
43							2,250	2,513	2,776	3,039	3,302	3,564	1
Basis: No. trees	1	7	38	88	110	139	127	103	58	16	12	4	703

Block indicates extent of basic data.
Derived from: $V = 0.013887\ D^2H - 114.596390$ for D^2H larger than 20,000.
Standard error of estimate: ± 22.79 percent.
Diameter classes full-inch; e. g., 20-inch class includes 20.0 to 20.9.

Table 5b. --Volumes in board-feet Scribner rule, old-growth ponderosa pines
Arizona and New Mexico

Board-feet inside bark
Merchantable stem excluding stump and top

Top diameter variable
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Total height in feet											Basis: Trees
	40	50	60	70	80	90	100	110	120	130	140	
	Volume in board-feet											No.
12	31	49	68	87	105	124	143					21
13	43	65	87	108	130	152	174					25
14	56	82	107	132	157	182	207					18
15	71	100	128	157	186	215	247					26
16	86	119	151	184	216	254	297					28
17	102	139	176	212	254	302	350	398				30
18	120	161	202	246	299	353	406	460				24
19	138	183	229	287	347	406	466	526	585			27
20		207	265	331	397	463	529	595	660	726		25
21		232	305	377	450	522	594	667	739	812		39
22		267	346	425	505	584	663	743	822	901		29
23		303	389	476	562	649	735	822	909	995		23
24			435	529	623	717	811	905	999	1,093		30
25			482	583	685	787	889	991	1,093	1,195		27
26			530	640	750	860	970	1,080	1,191	1,301		35
27			581	700	818	937	1,055	1,174	1,292	1,410		28
28			634	761	888	1,016	1,143	1,270	1,397	1,525	1,652	33
29			688	825	961	1,097	1,234	1,370	1,506	1,643	1,779	20
30			745	890	1,036	1,182	1,328	1,473	1,619	1,765	1,911	23
31			803	958	1,114	1,269	1,425	1,580	1,736	1,891	2,047	23
32				1,029	1,194	1,360	1,525	1,691	1,856	2,021	2,187	30
33				1,101	1,277	1,453	1,628	1,804	1,980	2,156	2,332	20
34				1,176	1,362	1,549	1,735	1,921	2,108	2,294	2,481	21
35				1,252	1,450	1,647	1,845	2,042	2,239	2,437	2,634	15
36				1,331	1,540	1,749	1,957	2,166	2,375	2,584	2,792	22
37				1,412	1,633	1,853	2,073	2,294	2,514	2,734	2,955	18
38				1,496	1,728	1,960	2,192	2,425	2,657	2,889	3,121	21
39				1,581	1,826	2,070	2,315	2,559	2,803	3,048	3,292	12
40					1,926	2,183	2,440	2,697	2,954	3,211	3,468	8
41					2,029	2,299	2,568	2,838	3,108	3,378	3,648	9
42						2,417	2,700	2,983	3,266	3,549	3,832	3
43						2,538	2,835	3,131	3,428	3,724	4,020	6
44						2,662	2,973	3,283	3,593	3,903	4,213	1
45						2,789	3,114	3,438	3,762	4,087	4,411	2
46						2,919	3,258	3,596	3,935	4,274	4,613	2
47							3,405	3,758	4,112	4,465	4,819	1
Basis: No. trees	8	33	53	94	120	126	123	103	44	19	2	725

Block indicates extent of basic data.
Derived from: $V = 0.015666\ D^2H - 129.672480$ for D^2H larger than 22, 900.
Standard error of estimate: ± 16.17 percent.
Diameter classes full-inch; e. g. 20-inch class includes 20.0 to 20.9.

Table 6a. --Volumes in board-feet Scribner Rule, blackjack ponderosa pines
Arizona and New Mexico

Board-feet inside bark
Merchantable stem excluding stump and top

Top diameter variable
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Number of merchantable 16-foot logs													Basis: Trees
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	
	Volume in board-feet													No.
12	43	61	78	96	114									32
13	49	70	90	111	131	152								33
14	55	79	103	126	150	174								32
15	62	89	116	143	170	200	236							33
16	69	100	131	161	193	234	275	316						32
17	77	111	146	180	224	270	316	361						41
18		124	162	205	256	307	359	410	461					36
19		136	179	233	290	347	404	461	518					30
20		150	200	263	326	389	452	515	578					34
21		164	225	295	364	433	503	572	641					26
22		179	252	328	404	480	556	632	707					37
23		196	279	362	445	528	611	694	777	859				26
24		218	308	398	488	578	668	758	849	939				32
25			338	436	533	631	728	826	924	1,021	1,119			24
26				475	580	685	791	896	1,002	1,107	1,212	1,318		30
27				515	629	742	856	969	1,083	1,196	1,310	1,423		23
28				557	679	801	923	1,045	1,167	1,288	1,410	1,532		27
29				601	731	862	992	1,123	1,254	1,384	1,515	1,645	1,776	19
30				646	785	925	1,065	1,204	1,344	1,483	1,623	1,762	1,902	24
31				692	841	990	1,139	1,288	1,437	1,586	1,734	1,883	2,032	18
32				740	899	1,057	1,216	1,374	1,533	1,691	1,850	2,008	2,167	18
33				790	958	1,127	1,295	1,463	1,632	1,800	1,969	2,137	2,305	15
34				841	1,019	1,198	1,377	1,555	1,734	1,912	2,091	2,270	2,448	21
35				893	1,082	1,272	1,461	1,650	1,839	2,028	2,217	2,406	2,595	15
36					1,147	1,347	1,547	1,747	1,947	2,147	2,347	2,546	2,746	22
37					1,214	1,425	1,636	1,847	2,058	2,269	2,480	2,691	2,902	9
38					1,282	1,505	1,727	1,949	2,172	2,394	2,617	2,839	3,061	4
39						1,587	1,821	2,055	2,289	2,523	2,757	2,991	3,225	4
40							1,917	2,163	2,409	2,655	2,901	3,147	3,393	3
41							2,015	2,274	2,532	2,790	3,049	3,307	3,566	2
42							2,116	2,387	2,658	2,929	3,200	3,471	3,742	0
43							2,219	2,503	2,787	3,071	3,355	3,639	3,923	1
Basis: No. trees	21	43	77	93	92	117	87	78	55	17	18	4	1	703

Block indicates extent of basic data.
Derived from: $V = 0.300081 D^2H - 52.090112$ for D^2H larger than 800.
Standard error of estimate: ± 16.46 percent.
Diameter classes full-inch; e. g. 20-inch class includes 20.0 to 20.9.

Table 6b. --Volumes in board-feet Scribner Rule, old-growth ponderosa pines
Arizona and New Mexico

Board-feet inside bark
Merchantable stem excluding stump and top

Top diameter variable
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Number of merchantable 16-foot logs													Basis: Trees
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	
	Volume in board-feet													No.
12	38	60	81	103	124	146								21
13	45	70	95	121	146	171	196							25
14	53	82	111	140	169	198	227							18
15	61	94	127	161	194	227	260	292						26
16	70	108	145	183	220	258	294	337						28
17	79	122	164	206	248	290	337	387						30
18		136	184	231	278	328	384	440	496					24
19		152	205	257	309	371	434	496	558	620				27
20		169	227	285	349	417	486	554	623	692	760			25
21		186	250	314	390	465	541	616	691	767	842	918		39
22			274	350	433	515	598	681	763	846	929	1,011		29
23				388	478	568	658	748	838	929	1,019	1,109		23
24				427	525	623	721	819	917	1,015	1,113	1,211		30
25				468	574	680	786	892	998	1,104	1,211	1,317		27
26				510	625	739	854	969	1,083	1,198	1,312	1,427		35
27				554	678	801	924	1,048	1,171	1,295	1,418	1,542		28
28				600	732	865	998	1,130	1,263	1,395	1,528	1,660		33
29				647	789	931	1,073	1,215	1,357	1,499	1,641	1,784		20
30				696	848	1,000	1,152	1,304	1,455	1,607	1,759	1,911	2,063	23
31				747	909	1,071	1,233	1,395	1,557	1,718	1,880	2,042	2,204	23
32				799	971	1,144	1,316	1,489	1,661	1,833	2,006	2,178	2,351	30
33					1,036	1,219	1,402	1,586	1,769	1,952	2,135	2,318	2,501	20
34					1,103	1,297	1,491	1,685	1,880	2,074	2,268	2,462	2,657	21
35					1,171	1,377	1,583	1,788	1,994	2,200	2,405	2,611	2,817	15
36					1,242	1,459	1,677	1,894	2,111	2,329	2,546	2,764	2,981	22
37					1,314	1,544	1,773	2,003	2,232	2,462	2,691	2,921	3,150	18
38						1,631	1,872	2,114	2,356	2,598	2,840	3,082	3,324	21
39						1,720	1,974	2,229	2,484	2,738	2,993	3,248	3,502	12
40						1,811	2,079	2,346	2,614	2,882	3,150	3,417	3,685	8
41						1,905	2,186	2,467	2,748	3,029	3,310	3,591	3,872	9
42							2,295	2,590	2,885	3,180	3,475	3,769	4,064	3
43							2,408	2,717	3,025	3,334	3,643	3,952	4,261	6
44							2,523	2,846	3,169	3,492	3,815	4,139	4,462	1
45							2,640	2,978	3,316	3,654	3,992	4,330	4,668	2
46							2,760	3,113	3,466	3,819	4,172	4,525	4,878	2
47								3,251	3,620	3,988	4,356	4,724	5,093	1
Basis: No. trees	10	27	46	62	72	87	129	107	95	62	22	6	0	725

Block indicates extent of basic data.
Derived from: $V = 0.326427 D^2H - 62.962331$ for D^2H larger than 1,130.
Standard error of estimate: ± 12.98 percent.
Diameter classes full-inch; e. g. 20-inch class includes 20.0 to 20.9

Table 7a. --Volumes in board-feet International 1/4-inch Rule, blackjack ponderosa pines
Arizona and New Mexico

Board-feet inside bark
Merchantable stem excluding stump and top

Top diameter variable
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Total height in feet												Basis: Trees
	30	40	50	60	70	80	90	100	110	120	130	140	
	Volume in board-feet												No.
12	18	36	54	73	91	109	128						32
13	27	48	70	91	112	134	155						33
14	37	61	86	111	135	160	185	212					32
15	47	75	104	132	160	188	221	255					33
16		90	122	154	186	223	262	301					32
17		106	142	178	218	262	305	349	393				41
18		123	163	205	254	303	352	400	449				36
19		141	186	238	292	346	400	455	509				30
20			212	272	332	392	452	512	572				34
21			242	308	374	440	506	572	638				26
22			273	345	418	490	562	634	707				37
23			306	385	464	542	621	700	779	858			26
24			340	426	512	597	683	769	854	940			32
25				469	562	654	747	840	933	1,025	1,118		24
26				513	613	714	814	914	1,014	1,115	1,215	1,315	30
27				560	667	775	883	991	1,099	1,207	1,315	1,423	23
28				607	723	839	955	1,071	1,187	1,303	1,419	1,535	27
29				657	781	905	1,030	1,154	1,278	1,402	1,526	1,651	19
30				708	841	974	1,107	1,239	1,372	1,505	1,638	1,770	24
31				762	903	1,045	1,186	1,328	1,470	1,611	1,753	1,894	18
32				816	967	1,118	1,269	1,419	1,570	1,721	1,871	2,022	18
33				873	1,033	1,193	1,353	1,513	1,674	1,834	1,994	2,154	15
34					1,101	1,271	1,441	1,610	1,780	1,950	2,120	2,290	21
35					1,171	1,351	1,531	1,710	1,890	2,070	2,250	2,430	15
36					1,243	1,433	1,623	1,813	2,003	2,193	2,383	2,574	22
37					1,317	1,517	1,718	1,919	2,119	2,320	2,521	2,721	9
38					1,393	1,604	1,816	2,027	2,239	2,450	2,662	2,873	4
39						1,693	1,916	2,138	2,361	2,584	2,806	3,029	4
40							2,019	2,253	2,487	2,721	2,955	3,189	3
41							2,124	2,370	2,615	2,861	3,107	3,353	2
42							2,232	2,490	2,747	3,005	3,263	3,521	0
43							2,342	2,612	2,882	3,152	3,422	3,692	1
Basis: No. trees	1	7	38	88	110	139	127	103	58	16	12	4	703

Block indicates extent of basic data.
Derived from: $V = 0.014270\ D^2H - 87.992784$ for D^2H larger than 20,000.
Standard error of estimate: ± 21.52 percent.
Diameter classes full-inch; e. g., 20-inch class includes 20.0 to 20.9.

Table 7b. --Volumes in board-feet International 1/4-inch rule, old-growth ponderosa pines
Arizona and New Mexico

Board-feet inside bark
Merchantable stem excluding stump and top

Top diameter variable
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Total height in feet											Basis: Trees
	40	50	60	70	80	90	100	110	120	130	140	
	Volume in board-feet											No.
12	40	61	83	105	127	149	171					21
13	54	80	105	131	156	182	207					25
14	70	99	129	158	187	217	246					18
15	87	120	154	187	221	255	290					26
16	104	143	181	219	257	298	342					28
17	124	166	209	252	298	347	396	445				30
18	144	192	239	289	344	399	454	509				24
19	165	218	271	332	393	454	515	576	637			27
20		246	309	377	444	512	579	647	714	781		25
21		276	350	424	498	572	646	721	795	869		39
22		311	392	473	555	636	717	798	879	961		29
23		348	437	525	614	702	791	879	968	1,057		23
24			483	579	675	772	868	964	1,060	1,157		30
25			531	635	739	844	948	1,052	1,157	1,261		27
26			581	694	806	919	1,031	1,144	1,257	1,369		35
27			633	754	875	997	1,118	1,239	1,361	1,482		28
28			687	817	947	1,078	1,208	1,338	1,469	1,599	1,729	33
29			743	882	1,022	1,161	1,301	1,441	1,580	1,720	1,859	20
30			800	950	1,099	1,248	1,397	1,546	1,696	1,845	1,994	23
31			860	1,019	1,178	1,337	1,497	1,656	1,815	1,974	2,133	23
32				1,091	1,260	1,430	1,599	1,769	1,938	2,108	2,277	30
33				1,165	1,345	1,525	1,705	1,885	2,065	2,245	2,425	20
34				1,241	1,432	1,623	1,814	2,005	2,196	2,387	2,578	21
35				1,320	1,522	1,724	1,927	2,129	2,331	2,533	2,735	15
36				1,401	1,615	1,828	2,042	2,256	2,469	2,683	2,897	22
37				1,484	1,710	1,935	2,161	2,386	2,612	2,837	3,063	18
38				1,569	1,807	2,045	2,283	2,520	2,758	2,996	3,234	21
39				1,657	1,907	2,158	2,408	2,658	2,908	3,159	3,409	12
40					2,010	2,273	2,536	2,799	3,062	3,325	3,589	8
41					2,115	2,391	2,668	2,944	3,220	3,496	3,773	9
42						2,513	2,802	3,092	3,382	3,672	3,961	3
43						2,637	2,940	3,244	3,547	3,851	4,154	6
44						2,764	3,082	3,399	3,717	4,034	4,352	1
45						2,894	3,226	3,558	3,890	4,222	4,554	2
46						3,027	3,373	3,720	4,067	4,414	4,761	2
47							3,524	3,886	4,248	4,610	4,972	1
Basis: No. trees	8	33	53	94	120	126	123	103	44	19	2	725

Block indicates extent of basic data.
Derived from: $V = 0.016041\ D^2H - 95.013379$ for D^2H larger than 21,800.
Standard error of estimate: ± 15.70 percent.
Diameter classes full-inch; e. g. 20-inch class includes 20.0 to 20.9.

Table 8a. --Volumes in board-feet International 1/4-inch Rule, blackjack ponderosa pines
Arizona and New Mexico

Board-feet inside bark
Merchantable stem excluding stump and top

Top diameter variable
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Number of merchantable 16-foot logs													Basis: Trees
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	
	Volume in board-feet													No.
12	53	73	94	114	134									32
13	60	84	107	131	155	179								33
14	67	94	122	149	177	203								32
15	75	106	138	169	198	235	273							33
16	83	119	154	190	228	270	312	354						32
17	92	132	172	212	259	307	354	401						41
18		146	191	240	293	346	398	451	504					36
19		161	211	269	328	387	445	504	562					30
20		177	235	300	365	430	495	559	624					34
21		193	261	333	404	475	546	618	689					26
22		210	288	366	445	523	601	679	757					37
23		232	317	402	487	572	657	743	828	913				26
24		254	346	439	531	624	717	809	902	994				32
25			377	477	578	678	778	879	979	1,079	1,179			24
26				518	626	734	842	951	1,059	1,167	1,276	1,384		30
27				559	676	792	909	1,026	1,142	1,259	1,376	1,492		23
28				602	728	853	978	1,103	1,229	1,354	1,479	1,604		27
29				647	781	915	1,050	1,184	1,318	1,452	1,586	1,721	1,855	19
30				693	837	980	1,124	1,267	1,411	1,554	1,697	1,841	1,984	24
31				741	894	1,047	1,200	1,353	1,506	1,659	1,812	1,965	2,118	18
32				791	953	1,116	1,279	1,442	1,605	1,768	1,931	2,094	2,256	18
33				841	1,014	1,188	1,361	1,534	1,707	1,880	2,053	2,226	2,399	15
34				894	1,077	1,261	1,444	1,628	1,812	1,995	2,179	2,362	2,546	21
35				948	1,142	1,336	1,531	1,725	1,919	2,114	2,308	2,502	2,697	15
36					1,209	1,414	1,620	1,825	2,030	2,236	2,441	2,647	2,852	22
37					1,277	1,494	1,711	1,928	2,145	2,361	2,578	2,795	3,012	9
38					1,348	1,576	1,805	2,033	2,262	2,490	2,719	2,948	3,176	4
39						1,660	1,901	2,141	2,382	2,623	2,863	3,104	3,344	4
40							2,000	2,253	2,505	2,758	3,011	3,264	3,517	3
41							2,101	2,366	2,632	2,897	3,163	3,429	3,694	2
42							2,204	2,483	2,761	3,040	3,318	3,597	3,876	0
43							2,310	2,602	2,894	3,186	3,478	3,769	4,061	1
Basis: No. trees	21	43	77	93	92	117	87	78	55	17	18	4	1	703

Block indicates extent of basic data.
Derived from: $V = 0.308405 D^2H - 23.872559$ for D^2H larger than 700.
Standard error of estimate: ± 15.26 percent.
Diameter classes full-inch; e. g. 20-inch class includes 20.0 to 20.9.

Table 8b. --Volumes in board-feet International 1/4-inch Rule, old-growth ponderosa pines
Arizona and New Mexico

Board-feet inside bark
Merchantable stem excluding stump and top

Top diameter variable
Stump height 1.0 feet

Diameter breast height outside bark (Inches)	Number of merchantable 16-foot logs													Basis: Trees
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	
	Volume in board-feet													No.
12	48	73	98	123	148	173								21
13	56	86	115	144	173	203	232							25
14	65	99	133	166	200	234	268							18
15	75	113	152	191	229	268	306	345						26
16	85	129	173	216	260	304	347	391						28
17	96	145	194	243	293	342	391	435						30
18		163	217	272	327	382	432	485	542					24
19		181	242	303	364	419	478	542	606	669				27
20		200	268	335	402	462	532	602	672	743	813			25
21		220	294	369	438	511	588	665	743	820	897	974		39
22			323	404	478	562	647	732	816	901	985	1,070		29
23				438	524	616	708	801	893	985	1,078	1,170		23
24				472	572	672	773	873	973	1,074	1,174	1,274		30
25				513	622	731	839	948	1,057	1,166	1,274	1,383		27
26				557	674	792	909	1,026	1,144	1,261	1,379	1,496		35
27				602	728	855	981	1,108	1,234	1,361	1,487	1,613		28
28				649	785	920	1,056	1,192	1,328	1,463	1,599	1,735		33
29				697	843	988	1,134	1,279	1,425	1,570	1,716	1,861		20
30				747	903	1,058	1,214	1,369	1,525	1,680	1,836	1,991	2,147	23
31				799	965	1,131	1,297	1,463	1,629	1,794	1,960	2,126	2,292	23
32				853	1,029	1,206	1,382	1,559	1,736	1,912	2,089	2,265	2,442	30
33					1,096	1,283	1,471	1,658	1,846	2,034	2,221	2,409	2,596	20
34					1,164	1,363	1,562	1,761	1,960	2,159	2,358	2,557	2,755	21
35					1,234	1,445	1,655	1,866	2,077	2,287	2,498	2,709	2,919	15
36					1,306	1,529	1,752	1,974	2,197	2,420	2,642	2,865	3,088	22
37					1,380	1,615	1,851	2,086	2,321	2,556	2,791	3,026	3,261	18
38						1,704	1,952	2,200	2,448	2,696	2,943	3,191	3,439	21
39						1,796	2,056	2,317	2,578	2,839	3,100	3,361	3,621	12
40						1,889	2,163	2,438	2,712	2,986	3,260	3,534	3,809	8
41						1,985	2,273	2,561	2,849	3,137	3,425	3,713	4,001	9
42							2,385	2,687	2,989	3,291	3,593	3,895	4,197	3
43							2,500	2,817	3,133	3,449	3,766	4,082	4,398	6
44							2,618	2,949	3,280	3,611	3,942	4,273	4,604	1
45							2,739	3,085	3,431	3,777	4,123	4,469	4,815	2
46							2,862	3,223	3,584	3,946	4,307	4,669	5,030	2
47								3,364	3,742	4,119	4,496	4,873	5,250	1
Basis: No. trees	10	27	46	62	72	87	129	107	95	62	22	6	0	725

Block indicates extent of basic data.
Derived from: $V = 0.334337 D^2H - 30.126317$ for D^2H larger than 1,386.
Standard error of estimate: ± 12.46 percent.
Diameter classes full-inch; e. g. 20-inch class includes 20.0 to 20.9.

Table 9a.--Scaling diameters of 16.5-foot logs of the average tree in each merchantable height and diameter class, blackjack ponderosa pine

Merchantable height logs	Diameter breast height	Position of log in the tree										
		1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
	Inches	Diameter inside bark in inches										
1.0	12.5	9										
	13.5	9										
	14.5	10										
	15.5	10										
1.5	12.5	9	8									
	13.5	10	9									
	14.5	10	9									
	15.5	11	9									
	16.5	11	10									
	17.5	12	10									
2.0	12.5	9		8								
	13.5	10		8								
	14.5	11		9								
	15.5	11		9								
	16.5	12		9								
	17.5	13		10								
	18.5	13		10								
	19.5	14		11								
	20.5	15		11								
	21.5	15		12								
	22.5	16		12								
	23.5	17		12								
	24.5	17		13								
2.5	12.5	10		8	8							
	13.5	11		9	8							
	14.5	11		9	8							
	15.5	12		10	8							
	16.5	13		10	9							
	17.5	13		11	9							
	18.5	14		11	10							
	19.5	15		12	10							
	20.5	15		12	10							
	21.5	16		13	11							
	22.5	17		13	11							
	23.5	17		14	12							
	24.5	18		14	12							
3.0	13.5	11		9		8						
	14.5	12		10		8						
	15.5	13		10		8						
	16.5	13		11		8						
	17.5	14		12		9						
	18.5	15		12		9						
	19.5	15		13		9						
	20.5	16		13		9						
	21.5	17		14		10						
	22.5	17		14		10						
	23.5	18		15		11						
	24.5	19		15		11						
	25.5	19		16		11						
	26.5	20		17		12						
	27.5	21		17		12						
	28.5	22		18		13						
	29.5	22		18		13						
	30.5	23		19		14						
	31.5	24		19		14						
	32.5	24		20		14						
	33.5	25		21		15						
	34.5	26		21		15						
	35.5	26		22		16						
3.5	15.5	13		11		9	8					
	16.5	14		12		9	8					
	17.5	15		12		10	9					
	18.5	15		13		10	9					
	19.5	16		13		10	9					
	20.5	17		14		11	9					
	21.5	17		15		11	9					
	22.5	18		15		12	10					
	23.5	19		16		12	10					
	24.5	19		17		13	10					
	25.5	20		17		13	11					
	26.5	21		18		13	11					
	27.5	21		18		14	12					
	28.5	22		19		14	12					
	29.5	23		20		15	12					
	30.5	23		20		15	13					
	31.5	24		21		15	13					
	32.5	25		21		16	13					
	33.5	26		22		16	14					
	34.5	26		23		17	14					
	35.5	27		23		17	15					
	36.5	28		24		18	15					
	37.5	28		25		18	15					
	38.5	29		25		18	16					
4.0	16.5	14		12		10		9				
	17.5	15		13		11		9				
	18.5	16		14		11		9				
	19.5	16		14		12		9				
	20.5	17		15		12		9				
	21.5	18		16		13		9				
	22.5	19		16		13		9				
	23.5	19		17		14		9				
	24.5	20		17		14		10				
	25.5	21		18		15		10				
	26.5	21		19		15		10				
	27.5	22		19		15		11				
	28.5	23		20		16		11				
	29.5	23		21		16		11				
	30.5	24		21		17		12				
	31.5	25		22		17		12				
	32.5	26		22		18		12				
	33.5	26		23		18		13				
	34.5	27		24		19		13				
	35.5	27		24		19		13				
	36.5	28		25		20		14				
	37.5	29		26		20		14				
	38.5	30		26		21		15				
4.5	18.5	16		15		12		10	9			
	19.5	17		15		13		10	9			
	20.5	18		16		13		10	9			
	21.5	18		16		14		11	9			
	22.5	19		17		14		11	9			
	23.5	20		18		15		12	10			
	24.5	20		18		15		12	10			
	25.5	21		19		16		12	10			
	26.5	22		20		16		13	10			
	27.5	22		20		17		13	11			
	28.5	23		21		18		13	11			
	29.5	24		21		18		14	11			
	30.5	25		22		19		14	11			
	31.5	25		23		19		14	12			
	32.5	26		23		20		15	12			
	33.5	27		24		20		15	12			
	34.5	27		25		21		16	12			
	35.5	28		25		21		16	13			
	36.5	29		26		22		16	13			
	37.5	29		26		22		17	13			
	38.5	30		27		23		17	13			
5.0	23.5	20		18		17		14		10		
	24.5	21		19		17		14		10		
	25.5	21		20		18		14		10		
	26.5	22		20		18		15		10		
	27.5	23		21		19		15		10		
	28.5	24		22		19		16		11		
	29.5	24		22		20		16		11		
	30.5	25		23		20		16		11		
	31.5	26		24		21		17		11		
	32.5	27		25		21		17		11		
	33.5	27		25		22		18		12		
	34.5	28		26		22		18		12		
	35.5	29		27		23		18		12		
	36.5	30		27		23		19		12		
	37.5	30		28		24		19		13		
	38.5	31		29		24		20		13		
5.5	26.5	22		21		19		17		12	10	
	27.5	23		22		20		17		13	10	
	28.5	24		22		21		18		13	10	
	29.5	25		23		21		18		13	11	
	30.5	26		24		22		19		14	11	
	31.5	26		25		22		19		14	11	
	32.5	27		25		23		20		15	12	
	33.5	28		26		23		20		15	12	
	34.5	29		27		24		21		15	12	
	35.5	30		28		25		21		16	13	
	36.5	30		28		25		22		16	13	
	37.5	31		29		26		22		16	14	
	38.5	32		30		27		22		17	14	
6.0	26.5	23		22		21		19		14		10
	27.5	23		22		21		19		15		10
	28.5	24		23		22		20		15		10
	29.5	25		24		22		20		16		11
	30.5	26		25		23		21		16		11
	31.5	27		25		24		21		17		12
	32.5	28		26		24		22		17		12
	33.5	28		27		25		22		17		12
	34.5	29		28		26		23		18		13
	35.5	30		28		26		23		18		13
	36.5	31		29		27		24		19		13
	37.5	32		30		27		24		19		14
	38.5	33		31		28		25		20		14

Table 9b. --Scaling diameters of 16.5-foot logs of the average tree in each merchantable height and diameter class, old-growth ponderosa pine

Merchant-able height logs	Diameter breast height	Position of log in the tree 1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
	Inches											
1.0	12.5	9										
	13.5	9										
	14.5	10										
	15.5	11										
	16.5	11										
1.5	12.5	9	8									
	13.5	10	9									
	14.5	11	9									
	15.5	11	10									
	16.5	12	11									
	17.5	13	11									
2.0	12.5	10		8								
	13.5	10		8								
	14.5	11		9								
	15.5	12		9								
	16.5	13		9								
	17.5	13		10								
	18.5	14		10								
	19.5	15		11								
	20.5	16		11								
	21.5	16		12								
2.5	12.5	10		8	8							
	13.5	11		9	8							
	14.5	12		9	9							
	15.5	12		10	9							
	16.5	13		11	9							
	17.5	14		11	9							
	18.5	15		12	10							
	19.5	15		12	11							
	20.5	16		13	11							
	21.5	17		[illegible]	12							
	22.5	18		14	12							
3.0	12.5	10		9		8						
	13.5	11		10		8						
	14.5	12		10		8						
	15.5	13		11		8						
	16.5	13		11		9						
	17.5	14		12		9						
	18.5	15		13		9						
	19.5	16		13		9						
	20.5	17		14		10						
	21.5	17		14		10						
	22.5	18		15		10						
	23.5	19		16		10						
	24.5	20		16		11						
	25.5	21		17		11						
	26.5	21		18		11						
	27.5	22		18		11						
	28.5	23		19		12						
3.5	13.5	12		10		9	8					
	14.5	12		11		9	8					
	15.5	13		12		10	8					
	16.5	14		12		10	9					
	17.5	15		13		10	9					
	18.5	15		13		11	9					
	19.5	16		14		11	9					
	20.5	17		15		11	9					
	21.5	18		15		12	10					
	22.5	18		16		12	10					
	23.5	19		17		13	10					
	24.5	20		17		13	11					
	25.5	21		18		13	11					
	26.5	22		19		14	11					
	27.5	23		19		15	12					
	28.5	23		20		15	12					
	29.5	24		21		16	12					
	30.5	25		22		16	12					
	31.5	26		22		17	13					
	32.5	27		23		18	13					
	33.5	27		24		18	13					
	34.5	28		25		19	14					
	35.5	29		25		19	14					
	36.5	30		26		20	14					
	37.5	31		27		21	15					
4.0	15.5	13		12		11		8				
	16.5	14		13		11		9				
	17.5	15		13		12		9				
	18.5	16		14		12		9				
	19.5	16		15		12		9				
	20.5	17		15		13		9				
	21.5	18		16		13		9				
	22.5	19		17		14		10				
	23.5	20		17		14		10				
	24.5	20		18		15		10				
	25.5	21		19		15		11				
	26.5	22		19		16		11				
	27.5	23		20		16		11				
	28.5	24		21		17		11				
	29.5	24		22		18		12				
	30.5	25		22		18		12				
	31.5	26		23		19		12				
	32.5	27		24		19		13				
4.0 (continued)	33.5	28		25		20		13				
	34.5	29		25		21		13				
	35.5	29		26		21		13				
	36.5	30		27		22		14				
	37.5	31		28		23		14				
	38.5	32		29		23		14				
	39.5	33		29		24		14				
	40.5	33		30		25		15				
	41.5	34		31		25		15				
4.5	18.5	16		14		13		11	9			
	19.5	17		15		13		11	9			
	20.5	17		16		14		11	9			
	21.5	18		16		14		12	9			
	22.5	19		17		15		12	10			
	23.5	20		18		15		12	10			
	24.5	20		19		16		13	10			
	25.5	21		19		17		13	10			
	26.5	22		20		17		13	11			
	27.5	23		21		18		14	11			
	28.5	24		22		18		14	11			
	29.5	25		22		19		14	11			
	30.5	26		23		20		15	12			
	31.5	26		24		20		15	12			
	32.5	27		25		21		15	12			
	33.5	28		25		21		16	12			
	34.5	29		26		22		16	13			
	35.5	30		27		23		17	13			
	36.5	31		28		23		17	13			
	37.5	32		28		24		17	13			
	38.5	33		29		25		18	14			
	39.5	34		30		25		18	14			
	40.5	34		31		26		18	14			
	41.5	35		32		27		19	14			
5.0	19.5	17		16		14		12		9		
	20.5	18		16		15		12		10		
	21.5	18		17		15		13		10		
	22.5	19		18		16		13		10		
	23.5	20		18		16		14		10		
	24.5	21		19		17		14		10		
	25.5	21		20		18		15		10		
	26.5	22		21		18		15		10		
	27.5	23		21		19		15		11		
	28.5	24		22		19		16		11		
	29.5	25		23		20		16		11		
	30.5	26		24		21		17		11		
	31.5	27		24		21		17		12		
	32.5	28		25		22		18		12		
	33.5	28		26		23		18		12		
	34.5	29		27		23		19		13		
	35.5	30		27		24		19		13		
	36.5	31		28		24		20		13		
	37.5	32		29		25		20		13		
	38.5	33		30		26		21		14		
	39.5	34		31		26		21		14		
	40.5	35		31		27		22		14		
	41.5	36		32		28		22		14		
5.5	20.5	16		17		15		13		11	9	
	21.5	18		18		16		14		11	10	
	22.5	19		18		17		14		12	10	
	23.5	20		19		17		15		12	10	
	24.5	21		20		18		15		12	10	
	25.5	22		21		18		16		13	10	
	26.5	23		21		19		16		13	10	
	27.5	23		22		20		17		13	10	
	28.5	24		23		20		17		13	11	
	29.5	25		24		21		18		14	11	
	30.5	26		24		22		18		14	11	
	31.5	27		25		22		19		14	11	
	32.5	28		26		23		19		15	12	
	33.5	29		26		24		20		15	12	
	34.5	30		27		24		20		16	12	
	35.5	30		28		25		21		16	13	
	36.5	31		29		26		22		16	13	
	37.5	32		29		26		22		17	13	
	38.5	33		30		27		23		17	13	
	39.5	34		31		28		23		17	14	
	40.5	36		32		28		24		18	14	
	41.5	37		33		29		25		18	14	
6.0	27.5	23		22		21		18		15		10
	28.5	24		23		21		19		15		10
	29.5	25		24		22		19		15		11
	30.5	26		25		23		20		16		11
	31.5	27		25		23		20		16		11
	32.5	28		26		24		21		17		11
	33.5	29		27		25		22		17		12
	34.5	30		28		25		22		18		12
	35.5	31		28		26		23		18		12
	36.5	32		29		27		24		18		12
	37.5	33		30		27		24		19		13
	38.5	34		31		28		25		19		13
	39.5	35		32		29		26		20		13
	40.5	36		32		29		26		20		13
	41.5	37		33		30		27		20		14

Table 10. --Percentage of total board-foot volume in each log of a tree, ponderosa pine

D.b.h. (inches) and tree height (logs)	Position of log in the tree											
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5
	Percent of total tree volume											
Trees 12 inches d.b.h.:												
1.0	100	--										
1.5	73	27										
2.0	59	--	41									
2.5	50	--	36	14								
3.0	41	--	34	--	25							
3.5	33	--	31	--	23	13						
Trees 20 inches d.b.h.:												
1.5	78	22										
2.0	68	--	32									
2.5	58	--	32	10								
3.0	49	--	33	--	18							
3.5	41	--	33	--	19	7						
4.0	37	--	32	--	20	--	11					
4.5	32	--	30	--	21	--	13	4				
5.0	28	--	27	--	22	--	15	--	8			
5.5	25	--	25	--	22	--	16	--	10	2		
6.0	24	--	22	--	22	--	17	--	12	--	3	
Trees 30 inches d.b.h.:												
2.5	65	--	28	7								
3.0	57	--	32	--	11							
3.5	49	--	32	--	15	4						
4.0	44	--	31	--	17	--	8					
4.5	39	--	29	--	19	--	10	3				
5.0	34	--	28	--	21	--	13	--	4			
5.5	30	--	26	--	21	--	14	--	7	2		
6.0	26	--	25	--	22	--	15	--	9	--	3	
6.5	24	--	23	--	22	--	15	--	11	--	4	1
Trees 40 inches d.b.h.:												
4.0	51	--	30	--	13	--	6					
4.5	46	--	28	--	16	--	8	2				
5.0	42	--	27	--	18	--	10	--	3			
5.5	37	--	27	--	19	--	11	--	5	1		
6.0	33	--	26	--	20	--	12	--	7	--	2	
6.5	30	--	24	--	20	--	12	--	9	--	4	1

Table 11. --Volumes of top wood between the upper limit of saw-log utilization and 4.0 inches d.i.b. as percentages of merchantable cubic-foot volume to 4.0-inch top, southwestern ponderosa pine

Diameter breast height class[1] (inches)	Age class		Diameter breast height class (inches)	Age class	
	Blackjacks	Old growth		Blackjacks	Old growth
	Percent			Percent	
12.0	35.5	28.3	28.0	4.0	3.3
14.0	21.8	19.1	30.0	3.7	3.1
16.0	14.2	13.3	32.0	3.2	2.9
18.0	9.4	8.9	34.0	2.8	2.7
20.0	7.2	6.2	36.0	2.4	2.5
22.0	5.9	5.1	38.0	2.0	2.3
24.0	5.0	4.2	40.0	1.6	2.1
26.0	4.5	3.7	42.0	1.2	2.0

[1] Full-inch diameter classes by 2-inch intervals, e.g., 20.0-inch class includes 19.0 to 20.9.

Myers, Clifford A.
1963. Volume, taper, and related tables for Southwestern ponderosa pine. Rocky Mountain Forest and Range Expt. Sta., U. S. Forest Serv. Res. Paper RM-2, 24 pp., illus.

Presents volume tables, taper tables, and the distribution of tree volumes among the logs of saw log trees. Volumes are in total cubic feet and cubic feet to a 4.0-inch top; board feet Scribner rule to a variable top, and board feet International 1/4-inch rule to a variable top. Tree heights are in feet and numbers of logs.

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April 1963 (Revised July 1972)

U. S. Forest Service
Research Paper RM-2

Volume, Taper, and Related Tables

for

Southwestern Ponderosa Pine

by

Clifford A. Myers

ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION
FORT COLLINS, COLORADO
FOREST SERVICE U. S. DEPARTMENT OF AGRICULTURE

ABSTRACT

Presents volume tables, taper tables, and the distribution of tree volumes among the logs of saw log trees. Volumes are in total cubic feet and cubic feet to a variable top. Tree heights are in feet and numbers of logs.

Keywords: *Pinus ponderosa*, forest measurement, tree volume tables.

U. S. Forest Service
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May 1963
(Revised July 1972)

VOLUME, TAPER AND RELATED TABLES
FOR
SOUTHWESTERN PONDEROSA PINE

by

Clifford A. Myers, Research Forester

Rocky Mountain Forest and Range Experiment Station[1]

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[1] Central headquarters maintained in cooperation with Colorado State University at Fort Collins.

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VOLUME, TAPER, AND RELATED TABLES FOR SOUTHWESTERN PONDEROSA PINE

by

Clifford A. Myers

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INTRODUCTION

The tables presented here give the basic mensurational values needed to measure ponderosa pines (Pinus ponderosa Laws.) in Arizona and New Mexico. They provide timber cruisers and growth estimators with the following:

1. Volumes in cubic feet to various limits of utilization.
2. Volumes in board feet, International 1/4-inch and Scribner log rules.
3. Scaling diameters of each log in trees of various diameter and merchantable height classes.
4. Distribution of board-foot volume among the logs of a tree.
5. Volumes of merchantable top wood as percentages of merchantable cubic feet to a 4.0-inch top.

Sample trees were measured in all areas of commercial ponderosa pine in Arizona and New Mexico.[2] Standards conformed to the needs of Forest Survey and the National Forests of the Southwestern Region.

Separate volume and taper tables were prepared for blackjack and old-growth ponderosa pines. Blackjacks and old-growth pines of equal diameter and height differ in taper and volume.[3] Blackjack pines are immature or young mature trees with dark bark and relatively rapid taper. Old-growth pines have yellowish bark, often in broad, flat plates, and less taper than blackjacks. Trees in these two groups have been tallied separately in cruising and other measurement work in the Southwest for many years.

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[2] Field measurements were made by personnel of the Southwestern Region, U. S. Forest Service, under the direction of Mr. Frank Bell.

[3] Hornibrook, Ezra M. Scribner volume tables for cut-over stands of ponderosa pine in Arizona. Jour. Agr. Res. 52: 961-974. 1936.

DEFINITIONS AND STANDARDS

Definitions of variables used in the tables, and of standards followed in field measurement and computations are as follows:

Diameter breast high (d.b.h.).--Measured to 0.1 inch outside bark 4.5 feet above ground level at the uphill side of the tree. Full-inch diameter classes, with class mid-points at the half-inch marks, were used in the tables (12.5, 13.5, etc.).

Scaling diameter of logs.--Average diameter inside bark to 0.1 inch, measured at the upper (small) end of logs or half-logs. Saw log diameter classes followed conventional scaling practice with the class mid-points at even inches (8.0, 9.0, etc.).

Minimum top diameter of sawtimber trees.--Diameter inside bark that represents average full saw log utilization of Southwestern ponderosa pine. Logs with a scaling diameter less than 7.6 inches (8-inch class) were not included in saw log volume, which conforms to the practice in most of Arizona and New Mexico. The average minimum top diameters, inside bark, used in computing tree volumes were:

Tree d.b.h. (Inches)	Minimum top saw log diameter (Inches)
12-13	8
14-21	9
22-26	10
27-31	11
32-35	12
36-39	13
40-42	14
43-45	15
46-47	16

Total height. --Measured from ground level at the uphill side of the tree upward to the tip. Forked, stag-topped, or other deformed trees were not included in the sample. Midpoints of the total height classes used in the tables were multiples of 10.0 feet.

Height in logs. --Measured from the top of a stump 1.0 foot high upward to the limit of saw log utilization. Each tree was divided into as many standard 16.5-foot-long logs as possible. An additional half-log, if present, was taken from the uppermost part of the merchantable length. Portions of the bole above the height of minimum top saw log diameter were included in the uppermost saw log if the standard length of the log or half-log ended within 4.0 feet above this height. This was done to avoid biased negative error in volumes[4] and positive error in top diameter averages.

EXPLANATION OF TABLES

The general definitions and standards given apply to all tables. Explanation of each type of table and suggestions for use are presented here.

VOLUME TABLES

Headings and footnotes with each volume table (tables 1a-8b) give the volume unit, type of height measurement, and utilization standards used in its compilation. Ten-foot or half-log height classes and full-inch diameter classes were used in all tables.

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[4] Chapman, Herman H., and Meyer, Walter H. Rules for measuring standard merchantable heights, p. 92. In Forest Mensuration. 522 pp., illus. New York: McGraw-Hill Book Co. 1950.

The volume tables were derived from linear regressions in V and D^2H, given in the footnotes, of the form:

$$V = a + b\ D^2H,\ \text{where:}$$

V = gross volume in the appropriate unit
D = diameter breast high outside bark
H = total height in feet or merchantable height in logs
a, b = regression constants

Equations for cubic volumes of sawtimber trees, with heights in feet, apply over the full range of the basic data. Other equations correctly expressed the relationship between volume and D^2H except for the smallest trees or the lowest values of D^2H. Tabular volumes for values of D^2H below the limits given with these equations were determined directly from the basic data as separate linear relationships.

The number of logs in a tree shown in the tables is not necessarily the number that will actually be cut from it. Instead, it is the number of logs between the stump and the height where minimum top diameter is reached. To locate the minimum top, the "4-foot rule" explained on page 2 should be used.

Volume of nonmerchantable logs below the height of minimum top diameter should be deducted according to the percentages in table 10, not by tallying fewer logs in the tree. For example, assume that a sound blackjack 30 inches in diameter has a bole length of 82.5 feet (5 logs) between the stump and the height where diameter inside bark is 11 inches. The tree has a gross volume of 1,344 board feet Scribner rule (table 6a). The top log is too limby to send to the sawmill. This log contains 4 percent of the board feet in the tree (table 10) and the other logs contain 96 percent. When 4 percent or 54 board feet is deducted, the tree contains 1,290 board feet. If the tree were tallied as a 30-inch, 4-log tree, it would be incorrectly credited with a volume of 1,065 board feet.

SCALING DIAMETERS OF LOGS IN A TREE

Tabulated scaling diameters (tables 9a, 9b) represent average tapers for the sample of trees measured. The range of tree diameters and heights is less than for the volume tables because too few trees were measured in some height and diameter classes to insure reliable averages.

Tree volumes obtained by summing the volumes of logs with the indicated scaling diameters will not equal tree volumes in the volume tables. Taper tables are constructed by averaging diameters at the taper points, while volume tables are based on averages of tree volumes. Tree volumes computed from the taper tables will usually differ from volume table values by less than 10 percent, however.

Top logs in the taper tables do not always have the minimum top scaling diameter appropriate for the size of tree. That is because the saw log trees were not utilized to a fixed top diameter, but in lengths that were multiples of 8.25 feet. For example, scaling diameters of top logs or half-logs of 20-inch blackjacks (table 9a) range from 9 inches (4.5-log trees) to 11 inches (2-log trees). However, most sample trees 20 inches in diameter were utilized to a 9-inch top.

Despite these limitations, taper tables are useful tools for tree measurement. One use is for estimating volume by log-quality classes. The logs of a tree usually differ in grade, but this difference cannot be shown by the values in a volume table. If the scaling diameter and grade of each log of a tree is known, volumes in each log-quality class can be determined.

PERCENTAGE OF TREE BOARD-FOOT VOLUME IN EACH LOG

The board-foot volume in each log-quality class can also be determined with the percentages from table 10. Each line in the body of the table gives the distribution of volume among the logs of a tree of specified diameter and merchantable length. In 30-inch, 3-log trees, the butt log contains 57 percent of the board feet, the middle log contains 32 percent, and the top log 11 percent. A 30-inch, 3-log blackjack contains 785 board feet Scribner rule (table 6a). The volume of each log, from the butt upwards, is 448, 251, and 86 board feet. These amounts can be assigned to the proper log-quality classes.

An important use of table 10 has already been explained in the description of the volume tables. Nonmerchantable logs below the height of minimum top diameter should be deducted from tree volume by means of the percentages shown, not by tallying fewer logs in the tree.

The percentages in table 10 can be used for both old-growth and blackjack ponderosa pines, and with both the Scribner and International 1/4-inch log rules. Percentages for diameters that are not included can be obtained by interpolation.

CONVERSION FACTORS FOR VOLUME OF MERCHANTABLE TOPS

Wood 4.0 inches in diameter or larger inside bark that is not harvested for saw logs is often suitable for pulpwood. Top wood volumes can be computed directly by means of the appropriate volume tables (tables 2a, 4a; 2b, 4b) but it is sometimes more convenient to obtain them by converting other measures of volume.

The conversion factors (table 11) were obtained by determining for each tree the percent volume of sapwood from the formula:

$$\frac{\text{Volume from upper limit of utilization for saw logs to 4.0 inches d.i.b.}}{\text{Merchantable cubic-foot volume, stump to 4.0-inch top}} \times 100$$

The resulting percentages were then smoothed graphically.

Each conversion factor is the average percentage of merchantable cubic-foot volume (tables 2a, 2b, 3a, 3b) left in the tops after saw log harvest. For example, a stand containing 1,000 merchantable cubic feet of wood in old-growth trees 13.0 to 14.9 inches diameter has 1000 × 0.191 or 191 cubic feet of usable top wood.

Table 1a.--Volumes of entire stem in cubic feet, blackjack ponderosa pines
Arizona and New Mexico

Cubic feet inside bark
Entire stem including stump and top

Total height above ground

Diameter breast height outside bark (Inches)	Total height in feet													Basis: Trees
	20	30	40	50	60	70	80	90	100	110	120	130	140	
	Volume in cubic feet													No.
5	1.69	2.24	2.79	3.35										10
6	2.13	2.90	3.67	4.44	5.21									20
7	2.64	3.67	4.69	5.72	6.74									11
8	3.22	4.54	5.86	7.18	8.49	9.81								12
9	3.88	5.53	7.17	8.82	10.5	12.2								19
10	4.61	6.62	8.63	10.6	12.8	15.1								14
11	5.41	7.82	10.2	12.8	15.6	18.4	21.2							22
12	6.29	9.14	12.1	15.3	18.6	21.9	25.2	28.5						34
13		10.6	14.2	18.1	21.9	25.7	29.6	33.4						33
14		12.2	16.6	21.0	25.4	29.9	34.3	38.7	43.1					32
15		14.1	19.1	24.2	29.2	34.3	39.3	44.4	49.4					33
16			21.8	27.5	33.3	39.0	44.7	50.4	56.2					32
17			24.7	31.1	37.6	44.0	50.4	56.9	63.3	69.8				41
18			27.7	34.9	42.1	49.3	56.5	63.7	70.9	78.1				36
19			30.9	38.9	46.9	54.9	62.9	70.9	78.9	86.9				30
20			34.3	43.1	51.9	60.8	69.6	78.4	87.3	96.1				34
21				47.5	57.2	67.0	76.7	86.4	96.1	106				26
22				52.1	62.8	73.4	84.1	94.7	105	116				37
23				57.0	68.6	80.2	91.8	103	115	127	138			26
24				62.0	74.6	87.3	99.9	113	125	138	150			32
25					81.0	94.6	108	122	136	149	163	177		24
26					87.5	102	117	132	147	161	176	191	206	30
27					94.3	110	126	142	158	174	190	206	222	23
28					101	118	136	153	170	187	204	221	238	27
29					109	127	145	164	182	200	219	237	255	19
30					116	136	155	175	195	214	234	253	273	24
31					124	145	166	187	208	228	249	270	291	18
32					132	154	177	199	221	243	265	288	310	18
33					141	164	188	211	235	259	282	306	329	15
34						174	199	224	249	274	299	324	349	21
35						184	211	237	264	290	317	343	370	15
36						195	223	251	279	307	335	363	391	22
37						206	235	265	295	324	354	383	413	9
38						217	248	279	311	342	373	404	435	4
39							261	294	327	360	393	425	458	4
40								309	344	378	413	447	482	3
41								325	361	397	434	470	506	2
42								341	379	417	455	493	531	0
43								357	397	437	476	516	556	1
Basis: No. trees	2	23	39	70	105	115	139	127	103	58	16	12	4	813

Block indicates extent of basic data.
Derived from: $V = 0.001824\ D^2H + 0.5870$ for D^2H to 6,000.
$V = 0.002103\ D^2H - 1.091458$ for D^2H larger than 6,000.
Standard error of estimate: ± 16.48 percent.
Diameter classes full-inch; e.g. 20-inch class includes 20.0 to 20.9.

Table 1b. --Volumes of entire stem in cubic feet, old-growth ponderosa pines
Arizona and New Mexico

Cubic feet inside bark
Entire stem including stump and top

Total height above ground

Diameter breast height outside bark (Inches)	Total height in feet											Basis: Trees
	40	50	60	70	80	90	100	110	120	130	140	
	Volume in cubic feet											No.
12	14.0	17.6	21.2	24.8	28.4	32.0	35.6					21
13	16.4	20.6	24.8	29.0	33.2	37.4	41.6					25
14	19.0	23.8	28.6	33.5	38.3	43.2	48.0					18
15	21.7	27.3	32.8	38.3	43.8	49.4	54.9					26
16	24.7	30.9	37.2	43.5	49.7	56.0	62.3					28
17	27.8	34.8	41.9	48.9	56.0	63.0	70.1	77.1				30
18	31.1	39.0	46.9	54.7	62.6	70.5	78.4	86.3				24
19	34.6	43.4	52.1	60.9	69.6	78.4	87.1	95.9	105			27
20		48.0	57.6	67.3	77.0	86.7	96.3	106	116	125		25
21		52.8	63.4	74.1	84.7	95.4	106	117	127	138		39
22		57.9	69.5	81.2	92.8	104	116	128	139	151		29
23		63.2	75.9	88.6	101	114	127	139	152	165		23
24			82.5	96.3	110	124	138	152	165	179		30
25			89.4	104	119	134	149	164	179	194		27
26			96.6	113	129	145	161	177	194	210		35
27			104	121	139	156	174	191	209	226		28
28			112	130	149	168	187	205	224	243	261	33
29			120	140	160	180	200	220	240	260	280	20
30			128	149	171	192	214	235	257	278	299	23
31			137	159	182	205	228	251	274	297	319	23
32				170	194	218	243	267	291	316	340	30
33				180	206	232	258	284	310	335	361	20
34				191	219	246	274	301	328	356	383	21
35				203	232	261	290	319	348	377	406	15
36				214	245	276	306	337	368	398	429	22
37				226	259	291	323	356	388	420	453	18
38				238	273	307	341	375	409	443	477	21
39				251	287	323	359	395	431	467	502	12
40					302	339	377	415	453	490	528	8
41					317	356	396	436	475	515	555	9
42						374	415	457	499	540	582	3
43						392	435	479	522	566	609	6
44						410	455	501	547	592	638	1
45						429	476	524	571	619	667	2
46						448	497	547	597	647	696	2
47							519	571	623	675	727	1
Basis: No. trees	8	33	53	94	120	126	123	103	44	19	2	725

Block indicates extent of basic data.
Derived from: $V = 0.002302\ D^2 H - 0.402357$.
Standard error of estimate: ± 11.44 percent.
Diameter classes full-inch; e. g. 20-inch class includes 20.0 to 20.9.

Table 2a. --Merchantable volumes in cubic feet to a 4.0-inch top, blackjack ponderosa pines
Arizona and New Mexico

Cubic feet inside bark
Merchantable stem excluding stump and top

Top diameter 4.0 inches inside bark
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Total height in feet													Basis: Trees
	20	30	40	50	60	70	80	90	100	110	120	130	140	
	Volume in cubic feet													No.
5	0.87	1.40	1.94	2.47										10
6	1.29	2.04	2.79	3.53	4.28									20
7	1.79	2.78	3.78	4.77	5.77									11
8	2.35	3.63	4.91	6.19	7.47	8.75								12
9	2.99	4.59	6.18	7.78	9.38	11.0								19
10	3.70	5.65	7.60	9.55	11.5	13.8								14
11	4.48	6.82	9.16	11.5	14.3	17.0	19.7							22
12	5.33	8.09	10.9	14.0	17.2	20.4	23.6	26.9						34
13		9.47	12.9	16.7	20.4	24.2	27.9	31.7						33
14		11.0	15.2	19.6	23.9	28.2	32.5	36.8	41.2					32
15		12.8	17.7	22.6	27.6	32.5	37.5	42.4	47.3					33
16			20.3	25.9	31.5	37.1	42.7	48.3	53.9					32
17			23.1	29.4	35.7	42.0	48.3	54.6	60.9	67.2				41
18			26.1	33.1	40.2	47.2	54.2	61.3	68.3	75.3				36
19			29.2	37.0	44.8	52.7	60.5	68.3	76.1	83.9				30
20			32.5	41.1	49.8	58.4	67.1	75.7	84.3	93.0				34
21				45.5	55.0	64.5	74.0	83.5	93.0	102				26
22				50.0	60.4	70.8	81.2	91.6	102	112				37
23				54.7	66.1	77.4	88.8	100	111	123	134			26
24				59.6	72.0	84.3	96.7	109	121	134	146			32
25					78.2	91.5	105	118	132	145	158	172		24
26					84.6	99.0	113	128	142	157	171	186	200	30
27					91.2	107	122	138	153	169	185	200	216	23
28					98.1	115	132	148	165	182	198	215	232	27
29					105	123	141	159	177	195	213	231	248	19
30					113	132	151	170	189	208	227	247	266	25
31					120	141	161	182	202	222	243	263	284	18
32					128	150	172	193	215	237	259	280	302	18
33					136	159	183	206	229	252	275	298	321	15
34						169	194	218	243	267	292	316	341	21
35						179	205	231	257	283	309	335	361	15
36						190	217	244	272	299	327	354	381	22
37						200	229	258	287	316	345	374	403	9
38						211	242	272	303	333	364	394	425	4
39							255	287	319	351	383	415	447	4
40								301	335	369	403	436	470	3
41								317	352	387	423	458	494	2
42								332	369	406	444	481	518	0
43								348	387	426	465	504	543	1
Basis: No. trees	2	23	39	70	105	115	139	127	103	58	16	12	4	813

Block indicates extent of basic data.
Derived from: $V = 0.001770 D^2H - 0.20550$ for D^2H to 6,500.
$V = 0.002056 D^2H - 2.061477$ for D^2H larger than 6,500.
Standard error of estimate: ± 14.81 percent.
Diameter classes full-inch; e.g. 20-inch class includes 20.0 to 20.9.

Table 2b. --Merchantable volumes in cubic feet to a 4.0-inch top, old-growth ponderosa pines
Arizona and New Mexico

Cubic feet inside bark
Merchantable stem excluding stump and top

Top diameter 4.0 inches inside bark
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Total height in feet											Basis: Trees
	40	50	60	70	80	90	100	110	120	130	140	
	Volume in cubic feet											No.
12	12.7	16.2	19.7	23.2	26.7	30.3	33.8					21
13	15.0	19.1	23.2	27.3	31.4	35.5	39.7					25
14	17.5	22.3	27.0	31.7	36.5	41.2	46.0					18
15	20.2	25.6	31.1	36.5	41.9	47.3	52.7					26
16	23.1	29.3	35.4	41.5	47.7	53.8	60.0					28
17	26.2	33.1	40.0	46.9	53.8	60.7	67.6	74.5				30
18	29.4	37.1	44.9	52.6	60.3	68.0	75.7	83.5				24
19	32.9	41.4	50.0	58.6	67.2	75.7	84.3	92.9	101			27
20		45.9	55.4	64.9	74.4	83.8	93.3	103	112	122		25
21		50.7	61.1	71.5	81.9	92.4	103	113	124	134		39
22		55.6	67.1	78.5	89.9	101	113	124	136	147		29
23		60.8	73.3	85.7	98.2	111	123	136	148	160		23
24			79.8	93.3	107	120	134	147	161	175		30
25			86.5	101	116	131	145	160	175	189		27
26			93.6	109	125	141	157	173	189	204		35
27			101	118	135	152	169	186	203	220		28
28			108	127	145	163	182	200	218	237	255	33
29			116	136	156	175	195	214	234	254	273	20
30			124	145	166	187	208	229	250	271	292	23
31			133	155	178	200	222	245	267	289	312	23
32				165	189	213	237	261	284	308	332	30
33				176	201	226	252	277	302	328	353	20
34				186	213	240	267	294	321	347	374	21
35				197	226	254	283	311	340	368	396	15
36				209	239	269	299	329	359	389	419	22
37				221	252	284	316	347	379	411	443	18
38				233	266	299	333	366	400	433	467	21
39				245	280	315	350	386	421	456	491	12
40					294	331	368	405	442	479	516	8
41					309	348	387	426	465	503	542	9
42						365	406	447	487	528	569	3
43						383	425	468	511	553	596	6
44						400	445	490	534	579	624	1
45						419	465	512	559	605	652	2
46						437	486	535	584	632	681	2
47							507	558	609	660	711	1
Basis: No. trees	8	33	53	94	120	126	123	103	44	19	2	725

Block indicates extent of basic data.
Derived from: V = 0.002255 D^2H - 1.440832.
Standard error of estimate: ± 11.73 percent.
Diameter classes full-inch; e. g. 20-inch class includes 20.0 to 20.9.

[illegible].--[illegible] feet to a 4.0-inch top, blackjack ponderosa pines
Arizona and New Mexico

Cubic feet inside bark
Merchantable stem excluding stump and top

Top diameter 4.0 inches inside bark
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Number of merchantable 16-foot logs													Basis: Trees
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	
	- - - - - Volume in cubic feet - - - - -													No.
12	14.0	17.6	21.2	24.8	28.4									32
13	15.2	19.4	23.6	27.8	32.0	36.1								33
14	16.5	21.3	26.1	31.0	35.8	40.7								32
15	17.9	23.4	28.9	34.4	40.0	45.4	50.7							33
16	19.3	25.6	31.8	38.1	44.4	50.4	56.4	62.4						32
17	20.9	27.9	35.0	42.0	48.9	55.6	62.4	69.2						41
18		30.4	38.3	46.1	53.7	61.2	68.8	76.3	83.9					36
19		33.0	41.5	50.3	58.7	67.1	75.5	83.9	92.3					30
20		35.8	45.4	54.7	64.0	73.3	82.6	91.9	101					34
21		38.7	49.2	59.3	69.6	79.8	90.0	100	110					26
22		41.7	53.0	64.2	75.4	86.6	97.8	109	120					37
23		44.9	57.1	69.3	81.5	93.7	106	118	130	143				26
24		48.1	61.3	74.6	87.9	101	114	128	141	154				32
25			65.8	80.1	94.5	109	123	138	152	166	181			24
26				85.9	101	117	132	148	163	179	195	210		30
27				91.8	109	125	142	159	175	192	209	226		23
28				98.0	116	134	152	170	188	206	224	242		27
29				104	124	143	162	181	201	220	239	258	278	19
30				111	132	152	173	193	214	234	255	276	296	24
31				118	140	162	184	206	228	250	271	293	315	18
32				125	148	172	195	218	242	265	288	312	335	18
33				132	157	182	207	232	256	281	306	331	356	15
34				140	166	192	219	245	271	298	324	350	377	21
35				148	175	203	231	259	287	315	343	370	398	15
36					185	214	244	273	303	332	362	391	421	22
37					195	226	257	288	319	350	381	412	443	9
38					205	238	270	303	336	369	401	434	467	4
39						250	284	319	353	388	422	457	491	4
40							298	335	371	407	443	480	516	3
41							313	351	389	427	465	503	541	2
42							328	368	407	447	487	527	567	0
43							343	385	426	468	510	552	594	1
Basis: No. trees	21	43	77	93	92	117	87	78	55	17	18	4	1	703

Block indicates extent of basic data.
Derived from: $V = 0.0460\ D^2H + 6.40$ for D^2H to 800.
$V = 0.044204\ D^2H + 8.266000$ for D^2H larger than 800.
Standard error of estimate: ± 12.81 percent.
Diameter classes full-inch; e.g. 20-inch class includes 20.0 to 20.9.

Table 3b. --Merchantable volumes in cubic feet to a 4.0-inch top, old-growth ponderosa pines
Arizona and New Mexico

Cubic feet inside bark
Merchantable stem excluding stump and top

Top diameter 4.0 inches inside bark
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Number of merchantable 16-foot logs													Basis: Trees
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	
	Volume in cubic feet													No.
12	13.8	17.7	21.7	25.7	29.6	33.6								21
13	15.1	19.7	24.3	29.0	33.6	38.2	42.8							25
14	16.5	21.8	27.2	32.5	37.8	43.2	48.5							18
15	18.0	24.1	30.2	36.3	42.4	48.5	54.6	60.3						26
16	19.7	26.6	33.5	40.4	47.2	54.1	60.7	66.9						28
17	21.4	29.1	36.9	44.7	52.4	59.9	66.9	73.9						30
18		31.9	40.5	49.2	57.8	65.6	73.5	81.3	89.1					24
19		34.8	44.4	54.0	63.0	71.7	80.4	89.1	97.8	107				27
20		37.8	48.5	58.9	68.5	78.1	87.7	97.3	107	117	126			25
21		41.0	52.7	63.7	74.3	84.9	95.4	106	117	127	138	148		39
22			57.2	68.7	80.3	91.9	103	115	127	138	150	161		29
23				74.0	86.6	99.3	112	125	137	150	162	175		23
24				79.5	93.2	107	121	134	148	162	176	189		30
25				85.2	100	115	130	145	160	174	189	204		27
26				91.2	107	123	139	155	171	188	204	220		35
27				97.3	115	132	149	167	184	201	218	236		28
28				104	122	141	159	178	197	216	234	252		33
29				110	130	150	170	190	210	230	250	270		20
30				117	138	160	181	202	224	245	266	287	309	23
31				124	147	170	192	215	238	260	283	306	329	23
32				132	156	180	204	228	252	277	301	325	349	30
33					165	191	216	242	267	293	319	344	370	20
34					174	201	229	256	283	310	337	365	392	21
35					184	213	241	270	299	328	357	386	414	15
36					194	224	255	285	316	346	376	407	437	22
37					204	236	268	300	332	365	397	429	461	18
38						248	282	316	350	384	418	452	485	21
39						261	296	332	368	403	439	475	510	12
40						273	311	348	386	423	461	498	536	8
41						287	326	365	405	444	483	523	562	9
42							341	383	424	465	507	548	589	3
43							357	400	444	487	530	573	617	6
44							373	418	464	509	554	600	645	1
45							390	437	484	532	579	626	674	2
46							406	456	505	555	604	654	703	2
47								475	527	578	630	682	733	1
Basis: No. trees	10	27	46	62	72	87	129	107	95	62	22	6	0	725

Block indicates extent of basic data.
Derived from: $V = 0.050666\ D^2H + 5.86680$ for D^2H to 1,000.
$V = 0.045736\ D^2H + 10.857212$ for D^2H larger than 1,000.
Standard error of estimate: ± 13.13 percent.
Diameter classes full-inch; e.g. 20-inch class includes 20.0 to 20.9.

Table 4a. --Merchantable volumes in cubic feet to the variable top limit of saw log utilization, blackjack ponderosa pines Arizona and New Mexico

Cubic feet inside bark
Merchantable stem excluding stump and top

Top diameter variable
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Total height in feet												Basis: Trees
	30	40	50	60	70	80	90	100	110	120	130	140	
	Volume in cubic feet												No.
12	2.83	6.02	9.22	12.4	15.6	18.8	22.0						32
13	4.43	8.15	11.9	15.6	19.3	23.0	26.8						33
14	6.14	10.4	14.7	19.0	23.3	27.6	31.9	36.2					32
15	7.98	12.9	17.8	22.7	27.6	32.5	37.4	42.3					33
16		15.5	21.1	26.6	32.2	37.8	43.3	48.9					32
17		18.3	24.5	30.8	37.1	43.3	49.6	55.8	62.1				41
18		21.2	28.2	35.2	42.2	49.2	56.2	63.2	70.2				36
19		24.3	32.1	39.9	47.6	55.4	63.2	70.9	78.7				30
20			36.2	44.8	53.4	61.9	70.5	79.1	87.7				34
21			40.5	49.9	59.4	68.8	78.2	87.7	97.1				26
22			45.0	55.3	65.7	76.0	86.3	96.7	107				37
23			49.7	61.0	72.2	83.5	94.8	106	117	129			26
24			54.6	66.8	79.1	91.4	104	116	128	140			32
25				73.0	86.2	99.5	113	126	139	153	166		24
26				79.3	93.7	108	122	137	151	165	180	194	30
27				86.0	101	117	132	148	163	179	194	210	23
28				92.8	109	126	143	159	176	192	209	226	27
29				99.9	118	135	153	171	189	207	224	242	19
30				107	126	145	164	183	202	221	240	259	24
31				115	135	155	176	196	216	237	257	277	18
32				123	144	166	187	209	231	252	274	295	18
33				131	154	177	200	223	245	268	291	314	15
34					163	188	212	236	261	285	309	334	21
35					173	199	225	251	276	302	328	354	15
36					184	211	238	265	293	320	347	374	22
37					194	223	252	281	309	338	367	395	9
38					205	236	266	296	326	357	387	417	4
39						248	280	312	344	376	408	440	4
40							295	328	362	395	429	462	3
41							310	345	380	415	451	486	2
42							325	362	399	436	473	510	0
43							341	380	419	457	496	534	1
Basis: No. trees	1	7	38	88	110	139	127	103	58	16	12	4	703

Block indicates extent of basic data.
Derived from: $V = 0.002043\ D^2H - 6.744303$.
Standard error of estimate: ± 16.17 percent.
Diameter classes full-inch; e. g. 20-inch class includes 20.0 to 20.9.

Table 4b. --Merchantable volumes in cubic feet to the variable top limit of saw log utilization,
old-growth ponderosa pines
Arizona and New Mexico

Cubic feet inside bark
Merchantable stem excluding stump and top

Top diameter variable
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Total height in feet											Basis: Trees
	40	50	60	70	80	90	100	110	120	130	140	
	Volume in cubic feet											No.
12	8.75	12.2	15.7	19.2	22.7	26.1	29.6					21
13	11.1	15.1	19.2	23.2	27.3	31.4	35.4					25
14	13.6	18.2	22.9	27.6	32.3	37.0	41.6					18
15	16.2	21.6	26.9	32.3	37.6	43.0	48.3					26
16	19.1	25.1	31.2	37.3	43.3	49.4	55.4					28
17	22.1	28.9	35.7	42.6	49.4	56.2	63.0	69.8				30
18	25.3	32.9	40.5	48.2	55.8	63.4	71.0	78.6				24
19	28.7	37.2	45.6	54.1	62.6	71.0	79.5	87.9	96.4			27
20		41.6	51.0	60.3	69.7	79.0	88.4	97.7	107	116		25
21		46.3	56.6	66.9	77.2	87.4	97.7	108	118	129		39
22		51.2	62.5	73.7	85.0	96.3	108	119	130	141		29
23		56.3	68.6	80.9	93.2	105	118	130	142	155		23
24			75.0	88.4	102	115	128	142	155	169		30
25			81.7	96.2	111	125	140	154	169	183		27
26			88.6	104	120	136	151	167	182	198		35
27			95.8	113	130	146	163	180	197	214		28
28			103	121	139	158	176	194	212	230	248	33
29			111	130	150	169	189	208	227	247	266	20
30			119	140	160	181	202	223	243	264	285	23
31			127	149	172	194	216	238	260	282	304	23
32				159	183	206	230	253	277	300	324	30
33				170	195	220	245	270	295	320	345	20
34				180	207	233	260	286	313	339	366	21
35				191	219	247	275	303	331	360	388	15
36				202	232	262	291	321	351	380	410	22
37				214	245	277	308	339	370	402	433	18
38				226	259	292	325	358	391	424	457	21
39				238	273	307	342	377	412	446	481	12
40					287	323	360	396	433	469	506	8
41					302	340	378	417	455	493	532	9
42						357	397	437	477	518	558	3
43						374	416	458	500	542	585	6
44						392	436	480	524	568	612	1
45						410	456	502	548	594	640	2
46						428	476	524	572	621	669	2
47							497	547	598	648	698	1
Basis: No. trees	8	33	53	94	120	126	123	103	44	19	2	725

Block indicates extent of basic data.
Derived from: $V = 0.002226\ D^2H - 5.161622$.
Standard error of estimate: ± 12.34 percent.
Diameter classes full-inch; e. g. 20-inch class includes 20.0 to 20.9.

Table 5a. --Volumes in board-feet Scribner rule, blackjack ponderosa pines
Arizona and New Mexico

Board-feet inside bark
Merchantable stem excluding stump and top

Top diameter variable
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Total height in feet												Basis: Trees
	30	40	50	60	70	80	90	100	110	120	130	140	
	Volume in board-feet												No.
12	18	33	48	62	77	92	107						32
[illegible]	25	43	60	77	94	112	129						33
14	33	53	73	93	113	133	153	177					32
15	42	65	87	110	133	[illegible]	186	219					33
16		77	103	128	[illegible]	[illegible]	[illegible]	263					32
17		90	119	[illegible]	183	226	268	311	353				41
18		103	136	171	218	266	313	361	408				36
19		118	154	202	255	308	361	413	466				30
[illegible]			177	[illegible]	294	352	411	469	527				34
21			206	271	335	399	463	527	592				26
22			237	307	378	448	518	588	659				37
23			269	346	422	499	576	652	729	806			26
24			302	386	469	552	636	719	802	886			32
[illegible]				427	518	608	698	788	879	969	1,059		24
[illegible]				471	568	666	763	861	958	1,056	1,153	1,251	30
27				516	621	726	831	936	1,041	1,146	1,251	1,356	23
28				562	675	788	901	1,013	1,126	1,239	1,352	1,465	27
29				611	731	852	973	1,094	1,215	1,336	1,456	1,577	19
30				661	790	919	1,048	1,177	1,306	1,436	1,565	1,694	24
31				712	850	988	1,126	1,263	1,401	1,539	1,677	1,815	18
32				765	912	1,059	1,206	1,352	1,499	1,646	1,792	1,939	18
33				820	976	1,132	1,288	1,444	1,600	1,756	1,911	2,067	15
34					1,042	1,208	1,373	1,538	1,704	1,869	2,034	2,199	21
35					1,110	1,285	1,461	1,636	1,811	1,986	2,161	2,336	15
36					1,180	1,365	1,550	1,735	1,921	2,106	2,291	2,476	22
37					1,252	[illegible]	1,643	1,838	2,034	2,229	2,424	2,619	9
38					1,326	1,532	1,738	1,944	2,150	2,355	2,561	2,767	4
39						1,619	1,835	2,052	2,269	2,485	2,702	2,919	4
40							1,935	2,163	2,391	2,619	2,847	3,074	3
[illegible]							2,038	2,277	2,516	2,755	2,995	3,234	2
42							2,143	2,394	2,645	2,895	3,146	3,397	0
43							[illegible]	2,513	2,776	3,039	3,302	3,564	1
Basis: No. trees	1	7	38	88	110	139	127	103	58	16	12	4	703

Block indicates extent of basic data.
Derived from: $V = 0.009481\ D^2H - 26.48230$ for D^2H to 20,000.
V = [illegible] D^2H - [illegible] for D^2H larger than 20,000.
Standard error of estimate: ± 22.79 percent.
Diameter classes full-inch; e.g. 20-inch class includes 20.0 to 20.9.

Table 5b.--Volumes in board-feet Scribner rule, old-growth ponderosa pines
Arizona and New Mexico

Board-feet inside bark
Merchantable stem excluding stump and top

Top diameter variable
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Total height in feet											Basis: Trees
	40	50	60	70	80	90	100	110	120	130	140	
	Volume in board-feet											No.
12	31	49	68	87	105	124	143					21
13	43	65	87	108	130	152	174					25
14	56	82	107	132	157	182	207					15
15	71	100	128	157	186	215	247					26
16	86	119	151	184	216	254	297					28
17	102	139	176	212	254	302	350	398				30
18	120	161	202	246	299	353	406	460				24
19	138	183	229	287	347	406	466	526	585			27
20		207	265	331	397	463	529	595	660	726		25
21		232	305	377	450	522	594	667	739	812		39
22		267	346	425	505	584	663	743	822	901		29
23		303	389	476	562	649	735	822	909	995		23
24			435	529	623	717	811	905	999	1,093		30
25			482	583	685	787	889	991	1,093	1,195		27
26			530	640	750	860	970	1,080	1,191	1,301		35
27			581	700	818	937	1,055	1,174	1,292	1,410		28
28			634	761	888	1,016	1,143	1,270	1,397	1,525	1,652	33
29			688	825	961	1,097	1,234	1,370	1,506	1,643	1,779	20
30			745	890	1,036	1,182	1,328	1,473	1,619	1,765	1,911	23
31			803	958	1,114	1,269	1,425	1,580	1,736	1,891	2,047	23
32				1,029	1,194	1,360	1,525	1,691	1,856	2,021	2,187	30
33				1,101	1,277	1,453	1,628	1,804	1,980	2,156	2,332	20
34				1,176	1,362	1,549	1,735	1,921	2,108	2,294	2,481	21
35				1,252	1,450	1,647	1,845	2,042	2,239	2,437	2,634	15
36				1,331	1,540	1,749	1,957	2,166	2,375	2,584	2,792	22
37				1,412	1,633	1,853	2,073	2,294	2,514	2,734	2,955	18
38				1,496	1,728	1,960	2,192	2,425	2,657	2,889	3,121	21
39				1,581	1,826	2,070	2,315	2,559	2,803	3,048	3,292	12
40					1,926	2,183	2,440	2,697	2,954	3,211	3,468	8
41					2,029	2,299	2,568	2,838	3,108	3,378	3,648	9
42						2,417	2,700	2,983	3,266	3,549	3,832	3
43						2,538	2,835	3,131	3,428	3,724	4,020	6
44						2,662	2,973	3,283	3,593	3,903	4,213	1
45						2,789	3,114	3,438	3,762	4,087	4,411	2
46						2,919	3,258	3,596	3,935	4,274	4,613	2
47							3,405	3,758	4,112	4,465	4,819	1
Basis: No. trees	8	33	53	94	120	126	123	103	44	19	2	725

Block indicates extent of basic data.
Derived from: $V = 0.011962\ D^2H - 44.1260$ for D^2H to 22,900.
$V = 0.015666\ D^2H - 129.672480$ for D^2H larger than 22,900.
Standard error of estimate: ± 16.17 percent.
Diameter classes full-inch; e.g. 20-inch class includes 20.0 to 20.9.

Table 6a. --Volumes in board-feet Scribner Rule, blackjack ponderosa pines
Arizona and New Mexico

Board-feet inside bark
Merchantable stem excluding stump and top

Top diameter variable
Stump height 1.0 foot

Diameter breast height outside bark (inches)	Number of merchantable 16-foot logs													Basis: Trees
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	
	Volume in board-feet													No.
12	43	61	78	96	114									32
13	[illegible]	70	[illegible]	111	131	[illegible]								33
14	55	79	103	126	[illegible]	174								32
15	62	89	116	143	170	200	236							33
16	69	100	131	161	193	234	275	316						32
17	77	111	146	180	224	270	316	361						41
18		124	162	205	256	307	359	410	461					36
19		156	179	233	[illegible]	347	404	461	518					30
20		150	200	263	326	389	452	515	578					34
21		164	225	295	364	433	503	572	641					26
22		179	252	328	404	480	556	632	707					37
23		196	279	362	445	528	611	694	777	859				26
24		218	308	398	488	578	668	758	849	939				32
25			338	436	533	631	728	826	924	1,021	1,119			24
26				475	580	685	791	896	1,002	1,107	1,212	1,318		30
27				515	629	742	856	969	1,083	1,196	1,310	1,423		23
28				557	679	801	923	1,045	1,167	1,288	1,410	1,532		27
29				601	731	862	992	1,123	1,254	1,384	1,515	1,645	1,776	19
30				646	785	925	1,065	1,204	1,344	1,483	1,623	1,762	1,902	24
31				692	841	990	1,139	1,288	1,437	1,586	1,734	1,883	2,032	18
32				740	899	1,057	1,216	1,374	1,533	1,691	1,850	2,008	2,167	18
33				790	958	1,127	1,295	1,463	1,632	1,800	1,969	2,137	2,305	15
34				841	1,019	1,198	1,377	1,555	1,734	1,912	2,091	2,270	2,448	21
35				893	1,082	1,272	1,461	1,650	1,839	2,028	2,217	2,406	2,595	15
36					1,147	1,347	1,547	1,747	1,947	2,147	2,347	2,546	2,746	22
37					1,214	1,425	1,636	1,847	2,058	2,269	2,480	2,691	2,902	9
38					1,282	1,505	1,727	1,949	2,172	2,394	2,617	2,839	3,061	4
39						1,587	1,821	2,055	2,289	2,523	2,757	2,991	3,225	4
40							1,917	2,163	2,409	2,655	2,901	3,147	3,393	3
41							2,015	2,274	2,532	2,790	3,049	3,307	3,566	2
42							2,116	2,387	2,658	2,929	3,200	3,471	3,742	0
43							2,219	2,503	2,787	3,071	3,355	3,639	3,923	1
Basis: No. trees	21	43	77	93	92	117	87	78	55	17	18	4	1	703

Block indicates extent of basic data.
Derived from: $V = 0.224793\ D^2H + 8.16560$ for D^2H to 800.
$V = 0.300081\ D^2H - 52.090112$ for D^2H larger than 800.
Standard error of estimate: ± 16.46 percent.
Diameter classes full-inch; e.g. 20-inch class includes 20.0 to 20.9.

Table 6b. --Volumes in board-feet Scribner Rule, old-growth ponderosa pines
Arizona and New Mexico

Board-feet inside bark
Merchantable stem excluding stump and top

Top diameter variable
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Number of merchantable 16-foot logs													Basis: Trees
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	
	Volume in board-feet													No.
12	38	60	81	103	124	146								21
13	45	70	95	121	146	171	196							25
14	53	82	111	140	169	198	227							18
15	61	94	127	161	194	227	260	292						26
16	70	108	145	183	220	258	294	337						28
17	79	122	164	206	248	290	337	387						30
18		136	184	231	278	328	384	440	496					24
19		152	205	257	309	371	434	496	558	620				27
20		169	227	285	349	417	486	554	623	692	760			25
21		186	250	314	390	465	541	616	691	767	842	918		39
22			274	350	433	515	598	681	763	846	929	1,011		29
23				388	478	568	658	748	838	929	1,019	1,109		23
24				427	525	623	721	819	917	1,015	1,113	1,211		30
25				468	574	680	786	892	998	1,104	1,211	1,317		27
26				510	625	739	854	969	1,083	1,198	1,312	1,427		35
27				554	678	801	924	1,048	1,171	1,295	1,418	1,542		28
28				600	732	865	998	1,130	1,263	1,395	1,528	1,660		33
29				647	789	931	1,073	1,215	1,357	1,499	1,641	1,784		20
30				696	848	1,000	1,152	1,304	1,455	1,607	1,759	1,911	2,063	23
31				747	909	1,071	1,233	1,395	1,557	1,718	1,880	2,042	2,204	23
32				799	971	1,144	1,316	1,489	1,661	1,833	2,006	2,178	2,351	30
33					1,036	1,219	1,402	1,586	1,769	1,952	2,135	2,318	2,501	20
34					1,103	1,297	1,491	1,685	1,880	2,074	2,268	2,462	2,657	21
35					1,171	1,377	1,583	1,788	1,994	2,200	2,405	2,611	2,817	15
36					1,242	1,459	1,677	1,894	2,111	2,329	2,546	2,764	2,981	22
37					1,314	1,544	1,773	2,003	2,232	2,462	2,691	2,921	3,150	18
38						1,631	1,872	2,114	2,356	2,598	2,840	3,082	3,324	21
39						1,720	1,974	2,229	2,484	2,738	2,993	3,248	3,502	12
40						1,811	2,079	2,346	2,614	2,882	3,150	3,417	3,685	8
41						1,905	2,186	2,467	2,748	3,029	3,310	3,591	3,872	9
42							2,295	2,590	2,885	3,180	3,475	3,769	4,064	3
43							2,408	2,717	3,025	3,334	3,643	3,952	4,261	6
44							2,523	2,846	3,169	3,492	3,815	4,139	4,462	1
45							2,640	2,978	3,316	3,654	3,992	4,330	4,668	2
46							2,760	3,113	3,466	3,819	4,172	4,525	4,878	2
47								3,251	3,620	3,988	4,356	4,724	5,093	1
Basis: No. trees	10	27	46	62	72	87	129	107	95	62	22	6	0	725

Block indicates extent of basic data.
Derived from: $V = 0.275784\ D^2H - 5.091250$ for D^2H to 1,130.
$V = 0.326427\ D^2H - 62.962331$ for D^2H larger than 1,130.
Standard error of estimate: ± 12.98 percent.
Diameter classes full-inch; e.g. 20-inch class includes 20.0 to 20.9.

Table 7a. --Volumes in board-feet International 1/4-inch Rule, blackjack ponderosa pines
Arizona and New Mexico

Board-feet inside bark
Merchantable stem excluding stump and top

Top diameter variable
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Total height in feet												Basis: Trees
	30	40	50	60	70	80	90	100	110	120	130	140	
	Volume in board-feet												No.
12	17	36	54	73	91	109	128						32
13	27	48	70	91	112	134	155						33
14	37	61	86	111	135	160	185	212					32
15	47	75	104	132	160	188	221	255					33
16		90	122	154	186	223	262	301					32
17		106	142	178	218	262	305	349	393				41
18		123	163	205	254	303	352	400	449				36
19		141	186	238	292	346	400	455	509				30
20			212	272	332	392	452	512	572				34
21			242	308	374	440	506	572	638				26
22			273	345	418	490	562	634	707				37
23			306	385	464	542	621	700	779	858			26
24			340	426	512	597	683	769	854	940			32
25				469	562	654	747	840	933	1,025	1,118		24
26				513	613	714	814	914	1,014	1,115	1,215	1,315	30
27				560	667	775	883	991	1,099	1,207	1,315	1,423	23
28				607	723	839	955	1,071	1,187	1,303	1,419	1,535	27
29				657	781	905	1,030	1,154	1,278	1,402	1,526	1,651	19
30				708	841	974	1,107	1,239	1,372	1,505	1,638	1,770	24
31				762	903	1,045	1,186	1,328	1,470	1,611	1,753	1,894	18
32				816	967	1,118	1,269	1,419	1,570	1,721	1,871	2,022	18
33				873	1,033	1,193	1,353	1,513	1,674	1,834	1,994	2,154	15
34					1,101	1,271	1,441	1,610	1,780	1,950	2,120	2,290	21
35					1,171	1,351	1,531	1,710	1,890	2,070	2,250	2,430	15
36					1,243	1,433	1,623	1,813	2,003	2,193	2,383	2,574	22
37					1,317	1,517	1,718	1,919	2,119	2,320	2,521	2,721	9
38					1,395	1,604	1,816	2,027	2,239	2,450	2,662	2,873	4
39						1,693	1,916	2,138	2,361	2,584	2,806	3,029	4
40							2,019	2,253	2,487	2,721	2,955	3,189	3
41							2,124	2,370	2,615	2,861	3,107	3,353	2
42							2,232	2,490	2,747	3,005	3,263	3,521	0
43							2,342	2,612	2,882	3,152	3,422	3,692	1
Basis: No. trees	1	7	38	88	110	139	127	103	58	16	12	4	703

Block indicates extent of basic data.
[illegible]: V = [illegible] for D^2H to 20,000.
$V = 0.014270 D^2H - 87.992784$ for D^2H larger than 20,000.
Standard error of estimate: ± 21.52 percent.
Diameter classes full-inch; e.g. 20-inch class includes 20.0 to 20.9.

Table 7b. --Volumes in board-feet International 1/4-inch rule, old-growth ponderosa pines

Arizona and New Mexico

Board-feet inside bark
Merchantable stem excluding stump and top

Top diameter variable
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Total height in feet: 40	50	60	70	80	90	100	110	120	130	140	Basis: Trees
	Volume in board-feet											No.
12	40	61	83	105	127	149	171					21
13	54	80	105	131	156	182	207					25
14	70	99	129	158	187	217	246					18
15	87	120	154	187	221	255	290					26
16	104	143	181	219	257	298	342					28
17	124	166	209	252	298	347	396	445				30
18	144	192	239	289	344	399	454	509				24
19	165	218	271	332	393	454	515	576	637			27
20		246	309	377	444	512	579	647	714	781		25
21		276	350	424	498	572	646	721	795	869		39
22		311	392	473	555	636	717	798	879	961		29
23		348	437	525	614	702	791	879	968	1,057		23
24			483	579	675	772	868	964	1,060	1,157		30
25			531	635	739	844	948	1,052	1,157	1,261		27
26			581	694	806	919	1,031	1,144	1,257	1,369		35
27			633	754	875	997	1,118	1,239	1,361	1,482		28
28			687	817	947	1,078	1,208	1,338	1,469	1,599	1,729	33
29			743	882	1,022	1,161	1,301	1,441	1,580	1,720	1,859	20
30			800	950	1,099	1,248	1,397	1,546	1,696	1,845	1,994	23
31			860	1,019	1,178	1,337	1,497	1,656	1,815	1,974	2,133	23
32				1,091	1,260	1,430	1,599	1,769	1,938	2,108	2,277	30
33				1,165	1,345	1,525	1,705	1,885	2,065	2,245	2,425	20
34				1,241	1,432	1,623	1,814	2,005	2,196	2,387	2,578	21
35				1,320	1,522	1,724	1,927	2,129	2,331	2,533	2,735	15
36				1,401	1,615	1,828	2,042	2,256	2,469	2,683	2,897	22
37				1,484	1,710	1,935	2,161	2,386	2,612	2,837	3,063	18
38				1,569	1,807	2,045	2,283	2,520	2,758	2,996	3,234	21
39				1,657	1,907	2,158	2,408	2,658	2,908	3,159	3,409	12
40					2,010	2,273	2,536	2,799	3,062	3,325	3,589	8
41					2,115	2,391	2,668	2,944	3,220	3,496	3,773	9
42						2,513	2,802	3,092	3,382	3,672	3,961	3
43						2,637	2,940	3,244	3,547	3,851	4,154	6
44						2,764	3,082	3,399	3,717	4,034	4,352	1
45						2,894	3,226	3,558	3,890	4,222	4,554	2
46						3,027	3,373	3,720	4,067	4,414	4,761	2
47							3,524	3,886	4,248	4,610	4,972	1
Basis: No. trees	8	33	53	94	120	126	123	103	44	19	2	725

Block indicates extent of basic data.
Derived from: $V = 0.0140\ D^2H - 48.0$ for D^2H to 21,800.
$V = 0.016041\ D^2H - 95.013379$ for D^2H larger than 21,800.
Standard error of estimate: ± 15.70 percent.
Diameter classes full-inch; e.g. 20-inch class includes 20.0 to 20.9.

Table 8a. --Volumes in board-feet International 1/4-inch Rule, blackjack ponderosa pines
Arizona and New Mexico

Board-feet inside bark
Merchantable stem excluding stump and top

Top diameter variable
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Number of merchantable 16-foot logs													Basis: Trees
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	
	Volume in board-feet													No.
12	53	73	94	114	134									32
13	60	84	107	131	155	179								33
14	67	94	122	149	177	203								32
15	[illegible]	106	135	169	195	235	273							33
16	83	119	154	190	228	270	312	354						32
17	92	132	172	212	259	307	354	401						41
18		146	191	240	293	346	398	451	504					36
19		161	211	269	328	387	445	504	562					30
20		177	[illegible]	300	365	430	495	559	624					34
21		193	261	333	404	475	546	618	689					26
22		210	288	366	445	523	601	679	757					37
23		232	317	402	487	572	657	743	828	913				26
24		254	346	439	531	624	717	809	902	994				32
25			377	477	578	678	778	879	979	1,079	1,179			24
26				518	626	734	842	951	1,059	1,167	1,276	1,384		30
27				559	676	792	909	1,026	1,142	1,259	1,376	1,492		23
28				602	728	853	978	1,103	1,229	1,354	1,479	1,604		27
29				647	781	915	1,050	1,184	1,318	1,452	1,586	1,721	1,855	19
30				693	837	980	1,124	1,267	1,411	1,554	1,697	1,841	1,984	24
31				741	894	1,047	1,200	1,353	1,506	1,659	1,812	1,965	2,118	18
32				791	953	1,116	1,279	1,442	1,605	1,768	1,931	2,094	2,256	18
33				841	1,014	1,188	1,361	1,534	1,707	1,880	2,053	2,226	2,399	15
34				894	1,077	1,261	1,444	1,628	1,812	1,995	2,179	2,362	2,546	21
35				948	1,142	1,336	1,531	1,725	1,919	2,114	2,308	2,502	2,697	15
36					1,209	1,414	1,620	1,825	2,030	2,236	2,441	2,647	2,852	22
37					1,277	1,494	1,711	1,928	2,145	2,361	2,578	2,795	3,012	9
38					1,348	1,576	1,805	2,033	2,262	2,490	2,719	2,948	3,176	4
39						1,660	1,901	2,141	2,382	2,623	2,863	3,104	3,344	4
40							2,000	2,253	2,505	2,758	3,011	3,264	3,517	3
41							2,101	2,366	2,632	2,897	3,163	3,429	3,694	2
42							2,204	2,483	2,761	3,040	3,318	3,597	3,876	0
43							2,310	2,602	2,894	3,186	3,478	3,769	4,061	1
Basis: No. trees	21	43	77	93	92	117	87	78	55	17	18	4	1	703

Block indicates extent of basic data.
[illegible] $V =$ [illegible] $D^2H +$ [illegible] for D^2H to 700.
$V =$ [illegible] $D^2H -$ [illegible] for D^2H larger than 700.
Standard error of estimate: ± 15.26 percent.
Diameter classes full-inch; e.g. 20-inch calss includes 20.0 to 20.9.

Table 8b. --Volumes in board-feet International 1/4-inch Rule, old-growth ponderosa pines
Arizona and New Mexico

Board-feet inside bark
Merchantable stem excluding stump and top

Top diameter variable
Stump height 1.0 feet

Diameter breast height outside bark (Inches)	Number of merchantable 16-foot logs													Basis: Trees
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	
	Volume in board-feet													No.
12	48	73	98	123	148	173								21
13	56	86	115	144	173	203	232							25
14	65	99	133	166	200	234	268							18
15	75	113	152	191	229	268	306	345						26
16	85	129	173	216	260	304	347	391						28
17	96	145	194	243	293	342	391	435						30
18		163	217	272	327	382	432	485	542					24
19		181	242	303	364	419	478	542	606	669				27
20		200	268	335	402	462	532	602	672	743	813			25
21		220	294	369	438	511	588	665	743	820	897	974		39
22			323	404	478	562	647	732	816	901	985	1,070		29
23				438	524	616	708	801	893	985	1,078	1,170		23
24				472	572	672	773	873	973	1,074	1,174	1,274		30
25				513	622	731	839	948	1,057	1,166	1,274	1,383		27
26				557	674	792	909	1,026	1,144	1,261	1,379	1,496		35
27				602	728	855	981	1,108	1,234	1,361	1,487	1,613		28
28				649	785	920	1,056	1,192	1,328	1,463	1,599	1,735		33
29				697	843	988	1,134	1,279	1,425	1,570	1,716	1,861		20
30				747	903	1,058	1,214	1,369	1,525	1,680	1,836	1,991	2,147	23
31				799	965	1,131	1,297	1,463	1,629	1,794	1,960	2,126	2,292	23
32				853	1,029	1,206	1,382	1,559	1,736	1,912	2,089	2,265	2,442	30
33					1,096	1,283	1,471	1,658	1,846	2,034	2,221	2,409	2,596	20
34					1,164	1,363	1,562	1,761	1,960	2,159	2,358	2,557	2,755	21
35					1,234	1,445	1,655	1,866	2,077	2,287	2,498	2,709	2,919	15
36					1,306	1,529	1,752	1,974	2,197	2,420	2,642	2,865	3,088	22
37					1,380	1,615	1,851	2,086	2,321	2,556	2,791	3,026	3,261	18
38						1,704	1,952	2,200	2,448	2,696	2,943	3,191	3,439	21
39						1,796	2,056	2,317	2,578	2,839	3,100	3,361	3,621	12
40						1,889	2,163	2,438	2,712	2,986	3,260	3,534	3,809	8
41						1,985	2,273	2,561	2,849	3,137	3,425	3,713	4,001	9
42							2,385	2,687	2,989	3,291	3,593	3,895	4,197	3
43							2,500	2,817	3,133	3,449	3,766	4,082	4,398	6
44							2,618	2,949	3,280	3,611	3,942	4,273	4,604	1
45							2,739	3,085	3,431	3,777	4,123	4,469	4,815	2
46							2,862	3,223	3,584	3,946	4,307	4,669	5,030	2
47								3,364	3,742	4,119	4,496	4,873	5,250	1
Basis: No. trees	10	27	46	62	72	87	129	107	95	62	22	6	0	725

Block indicates extent of basic data.
Derived from: $V = 0.320812\ D^2H - 2.126875$ for D^2H to 1,386.
$V = 0.334337\ D^2H - 30.126317$ for D^2H larger than 1,386.
Standard error of estimate: ± 12.46 percent.
Diameter classes full-inch; e.g. 20-inch class includes 20.0 to 20.9.

Table 9a.--Scaling diameters of 16.5-foot logs of the average tree in each merchantable height and diameter class, blackjack ponderosa pine

Merchantable height logs	Diameter breast height	Position of log in the tree 1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
	Inches	Diameter inside bark in inches										
1.0	12.5	9										
	13.5	9										
	14.5	10										
	15.5	10										
1.5	12.5	9	8									
	13.5	10	9									
	14.5	10	9									
	15.5	11	9									
	16.5	11	10									
	17.5	12	10									
2.0	12.5	9		8								
	13.5	10		8								
	14.5	11		9								
	15.5	11		9								
	16.5	12		9								
	17.5	13		10								
	18.5	13		10								
	19.5	14		11								
	20.5	15		11								
	21.5	15		12								
	22.5	16		12								
	23.5	17		12								
	24.5	17		13								
2.5	12.5	10		8	8							
	13.5	11		9	8							
	14.5	11		9	8							
	15.5	12		10	8							
	16.5	13		10	9							
	17.5	13		11	9							
	18.5	14		11	10							
	19.5	15		12	10							
	20.5	15		12	[illegible]							
	21.5	16		13	11							
	22.5	17		13	11							
	23.5	17		14	12							
	24.5	18		14	12							
3.0	13.5	11		9		8						
	14.5	12		10		8						
	15.5	13		10		8						
	16.5	13		11		8						
	17.5	14		12		9						
	18.5	15		12		9						
	19.5	15		13		9						
	20.5	16		13		9						
	21.5	17		14		10						
	22.5	17		14		10						
	23.5	18		15		11						
	24.5	19		15		11						
	25.5	19		16		11						
	26.5	20		17		12						
	27.5	21		17		12						
	28.5	22		18		13						
	29.5	22		18		13						
	30.5	23		19		14						
	31.5	24		19		14						
	32.5	24		20		14						
	33.5	25		21		15						
	34.5	26		21		15						
	35.5	26		22		16						
3.5	15.5	13		11		9	8					
	16.5	14		12		9	8					
	17.5	15		12		10	9					
	18.5	15		13		10	9					
	19.5	16		13		10	9					
	20.5	17		14		11	9					
	21.5	17		15		11	9					
	22.5	18		15		12	10					
	23.5	19		16		12	10					
	24.5	19		17		13	10					
	25.5	20		17		13	11					
	26.5	21		18		13	11					
	27.5	21		19		14	12					
	28.5	22		19		14	12					
	29.5	23		20		15	12					
	30.5	23		20		15	13					
	31.5	24		21		15	13					
	32.5	25		21		16	13					
	33.5	26		22		16	14					
	34.5	26		23		17	14					
	35.5	27		23		17	15					
	36.5	28		24		18	15					
	37.5	28		25		18	15					
	38.5	29		25		19	16					
4.0	16.5	14		12		10		9				
	17.5	15		13		11		9				
	18.5	16		14		11		9				
	19.5	16		14		12		9				
	20.5	17		15		12		9				
	21.5	18		16		13		9				
	22.5	19		16		13		9				
	23.5	19		17		14		9				
	24.5	20		17		14		10				
	25.5	21		18		15		10				
	26.5	21		19		15		10				
	27.5	22		19		15		11				
	28.5	23		20		16		11				
	29.5	23		21		16		11				
	30.5	24		21		17		12				
	31.5	25		22		17		12				
	32.5	26		22		18		12				
	33.5	26		23		18		13				
	34.5	27		24		19		13				
	35.5	27		24		19		13				
	36.5	28		25		20		14				
	37.5	29		26		20		14				
	38.5	30		26		21		15				
4.5	18.5	16		15		12		10	9			
	19.5	17		15		13		10	9			
	20.5	18		16		13		10	9			
	21.5	18		16		14		11	9			
	22.5	19		17		14		11	9			
	23.5	20		18		15		12	10			
	24.5	20		18		15		12	10			
	25.5	21		19		16		12	10			
	26.5	22		20		16		13	10			
	27.5	22		20		17		13	11			
	28.5	23		21		18		13	11			
	29.5	24		21		18		14	11			
	30.5	25		22		19		14	11			
	31.5	25		23		19		14	12			
	32.5	26		23		20		15	12			
	33.5	27		24		20		15	12			
	34.5	27		25		21		16	12			
	35.5	28		25		21		16	13			
	36.5	29		26		22		16	13			
	37.5	29		26		22		17	13			
	38.5	30		27		23		17	13			
5.0	23.5	20		18		17		14		10		
	24.5	21		19		17		14		10		
	25.5	21		20		18		14		10		
	26.5	22		20		18		15		10		
	27.5	23		21		19		15		10		
	28.5	24		22		19		16		11		
	29.5	24		22		20		16		11		
	30.5	25		23		20		16		11		
	31.5	26		24		21		17		11		
	32.5	27		25		21		17		11		
	33.5	27		25		22		18		12		
	34.5	28		26		22		18		12		
	35.5	29		27		23		18		12		
	36.5	30		27		23		19		12		
	37.5	30		28		24		19		13		
	38.5	31		29		24		20		13		
5.5	26.5	22		21		19		17		12	10	
	27.5	23		22		20		17		13	10	
	28.5	24		22		21		18		13	10	
	29.5	25		23		21		18		13	11	
	30.5	26		24		22		19		14	11	
	31.5	26		25		22		19		14	11	
	32.5	27		25		23		20		15	12	
	33.5	28		26		23		20		15	12	
	34.5	29		27		24		21		15	12	
	35.5	30		28		25		21		16	13	
	36.5	30		28		25		22		16	13	
	37.5	31		29		26		22		16	14	
	38.5	32		30		27		22		17	14	
6.0	26.5	23		22		21		19		14		10
	27.5	23		22		21		19		15		10
	28.5	24		23		22		20		15		10
	29.5	25		24		22		20		16		11
	30.5	26		25		23		21		16		11
	31.5	27		25		24		21		17		12
	32.5	28		26		24		22		17		12
	33.5	28		27		25		22		17		12
	34.5	29		28		26		23		18		13
	35.5	30		28		26		23		18		13
	36.5	31		29		27		24		19		13
	37.5	32		30		27		24		19		14
	38.5	33		31		28		25		20		14

Table 9b. --Scaling diameters of 16.5-foot logs of the average tree in each merchantable height and diameter class, old-growth ponderosa pine

Merchantable height logs	Diameter breast height	Position of log in the tree										
		1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
	Inches											
1.0	12.5	9										
	13.5	9										
	14.5	10										
	15.5	11										
	16.5	11										
1.5	12.5	9	8									
	13.5	10	9									
	14.5	11	9									
	15.5	11	10									
	16.5	12	11									
	17.5	13	11									
2.0	12.5	10		8								
	13.5	10		8								
	14.5	11		9								
	15.5	12		9								
	16.5	13		9								
	17.5	13		10								
	18.5	14		10								
	19.5	15		11								
	20.5	16		11								
	21.5	16		12								
2.5	12.5	10		8	8							
	13.5	11		9	8							
	14.5	12		9	9							
	15.5	12		10	9							
	16.5	13		11	9							
	17.5	14		11	9							
	18.5	15		12	10							
	19.5	15		12	11							
	20.5	16		13	11							
	21.5	17		13	12							
	22.5	18		14	12							
3.0	12.5	10		9		8						
	13.5	11		10		8						
	14.5	12		10		8						
	15.5	13		11		8						
	16.5	13		11		9						
	17.5	14		12		9						
	18.5	15		13		9						
	19.5	16		13		9						
	20.5	17		14		10						
	21.5	17		14		10						
	22.5	18		15		10						
	23.5	19		16		10						
	24.5	20		16		11						
	25.5	21		17		11						
	26.5	21		18		11						
	27.5	22		18		11						
	28.5	23		19		12						
3.5	13.5	12		10		9	8					
	14.5	12		11		9	8					
	15.5	13		12		10	8					
	16.5	14		12		10	9					
	17.5	15		13		10	9					
	18.5	15		13		11	9					
	19.5	16		14		11	9					
	20.5	17		15		11	9					
	21.5	18		15		12	10					
	22.5	18		16		12	10					
	23.5	19		17		13	10					
	24.5	20		17		13	11					
	25.5	21		18		13	11					
	26.5	22		19		14	11					
	27.5	23		19		15	12					
	28.5	23		20		15	12					
	29.5	24		21		16	12					
	30.5	25		22		16	12					
	31.5	26		22		17	13					
	32.5	27		23		18	13					
	33.5	27		24		18	13					
	34.5	28		25		19	14					
	35.5	29		25		19	14					
	36.5	30		26		20	14					
	37.5	31		27		21	15					
4.0	15.5	13		12		11		8				
	16.5	14		13		11		9				
	17.5	15		13		12		9				
	18.5	16		14		12		9				
	19.5	16		15		12		9				
	20.5	17		15		13		9				
	21.5	18		16		13		9				
	22.5	19		17		14		10				
	23.5	20		17		14		10				
	24.5	20		18		15		10				
	25.5	21		19		15		11				
	26.5	22		19		16		11				
	27.5	23		20		16		11				
	28.5	24		21		17		11				
	29.5	24		22		18		12				
	30.5	25		22		18		12				
	31.5	26		23		19		12				
	32.5	27		24		19		13				
4.0 (continued)	33.5	28		25		20		13				
	34.5	29		25		21		13				
	35.5	29		26		21		13				
	36.5	30		27		22		14				
	37.5	31		28		23		14				
	38.5	32		29		23		14				
	39.5	33		29		24		14				
	40.5	33		30		25		15				
	41.5	34		31		25		15				
4.5	18.5	16		14		13		11	9			
	19.5	17		15		13		11	9			
	20.5	17		16		14		11	9			
	21.5	18		16		14		12	9			
	22.5	19		17		15		12	10			
	23.5	20		18		15		12	10			
	24.5	20		19		16		13	10			
	25.5	21		19		17		13	10			
	26.5	22		20		17		13	11			
	27.5	23		21		18		14	11			
	28.5	24		22		18		14	11			
	29.5	25		22		19		14	11			
	30.5	26		23		20		15	12			
	31.5	26		24		20		15	12			
	32.5	27		25		21		15	12			
	33.5	28		25		21		16	12			
	34.5	29		26		22		16	13			
	35.5	30		27		23		17	13			
	36.5	31		28		23		17	13			
	37.5	32		28		24		17	13			
	38.5	33		29		25		18	14			
	39.5	34		30		25		18	14			
	40.5	34		31		26		18	14			
	41.5	35		32		27		19	14			
5.0	19.5	17		16		14		12		9		
	20.5	18		16		15		12		10		
	21.5	18		17		15		13		10		
	22.5	19		18		16		13		10		
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	34.5	29		27		23		19		13		
	35.5	30		27		24		19		13		
	36.5	31		28		24		20		13		
	37.5	32		29		25		20		13		
	38.5	33		30		26		21		14		
	39.5	34		31		26		21		14		
	40.5	35		31		27		22		14		
	41.5	36		32		28		22		14		
5.5	20.5	18		17		15		13		11	9	
	21.5	18		18		16		14		11	10	
	22.5	19		18		17		14		12	10	
	23.5	20		19		17		15		12	10	
	24.5	21		20		18		15		12	10	
	25.5	22		21		18		16		13	10	
	26.5	23		21		19		16		13	10	
	27.5	23		22		20		17		13	10	
	28.5	24		23		20		17		13	11	
	29.5	25		24		21		18		14	11	
	30.5	26		24		22		18		14	11	
	31.5	27		25		22		19		14	11	
	32.5	28		26		23		19		15	12	
	33.5	29		26		24		20		15	12	
	34.5	30		27		24		20		16	12	
	35.5	30		28		25		21		16	13	
	36.5	31		29		26		22		16	13	
	37.5	32		29		26		22		17	13	
	38.5	33		30		27		23		17	13	
	39.5	34		31		28		23		17	14	
	40.5	36		32		28		24		18	14	
	41.5	37		33		29		25		18	14	
6.0	27.5	23		22		21		18		15		10
	28.5	24		23		21		19		15		10
	29.5	25		24		22		19		15		11
	30.5	26		25		23		20		16		11
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	34.5	30		28		25		22		18		12
	35.5	31		28		26		23		18		12
	36.5	32		29		27		24		18		12
	37.5	33		30		27		24		19		13
	38.5	34		31		28		25		19		13
	39.5	35		32		29		26		20		13
	40.5	36		32		29		26		20		13
	41.5	37		33		30		27		20		14

Table 10. --Percentage of total board-foot volume in each log of a tree, ponderosa pine

D.b.h. (inches) and tree height (logs)	Position of log in the tree											
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5
	Percent of total tree volume											
Trees 12 inches d.b.h.:												
1.0	100	--										
1.5	73	27										
2.0	59	--	41									
2.5	50	--	36	14								
3.0	41	--	34	--	25							
3.5	33	--	31	--	23	13						
Trees 20 inches d.b.h.:												
1.5	78	22										
2.0	68	--	32									
2.5	58	--	32	10								
3.0	49	--	33	--	18							
3.5	41	--	33	--	19	7						
4.0	37	--	32	--	20	--	11					
4.5	32	--	30	--	21	--	13	4				
5.0	28	--	27	--	22	--	15	--	8			
5.5	25	--	25	--	22	--	16	--	10	2		
6.0	24	--	22	--	22	--	17	--	12	--	3	
Trees 30 inches d.b.h.:												
2.5	65	--	28	7								
3.0	57	--	32	--	11							
3.5	49	--	32	--	15	4						
4.0	44	--	31	--	17	--	8					
4.5	39	--	29	--	19	--	10	3				
5.0	34	--	28	--	21	--	13	--	4			
5.5	30	--	26	--	21	--	14	--	7	2		
6.0	26	--	25	--	22	--	15	--	9	--	3	
6.5	24	--	23	--	22	--	15	--	11	--	4	1
Trees 40 inches d.b.h.:												
4.0	51	--	30	--	13	--	6					
4.5	46	--	28	--	16	--	8	2				
5.0	42	--	27	--	18	--	10	--	3			
5.5	37	--	27	--	19	--	11	--	5	1		
6.0	33	--	26	--	20	--	12	--	7	--	2	
6.5	30	--	24	--	20	--	12	--	9	--	4	1

Table 11. --Volumes of top wood between the upper limit of saw-log utilization and 4.0 inches d.i.b. as percentages of merchantable cubic-foot volume to 4.0-inch top, southwestern ponderosa pine

Diameter breast height class[1] (inches)	Age class		Diameter breast height class (inches)	Age class	
	Blackjacks	Old growth		Blackjacks	Old growth
	Percent			Percent	
12.0	35.5	28.3	28.0	4.0	3.3
14.0	21.8	19.1	30.0	3.7	3.1
16.0	14.2	13.3	32.0	3.2	2.9
18.0	9.4	8.9	34.0	2.8	2.7
20.0	7.2	6.2	36.0	2.4	2.5
22.0	5.9	5.1	38.0	2.0	2.3
24.0	5.0	4.2	40.0	1.6	2.1
26.0	4.5	3.7	42.0	1.2	2.0

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[1] Full-inch diameter classes by 2-inch intervals, e.g., 20.0-inch class includes 19.0 to 20.9.

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1963 (rev. 1972).
Volume, taper, and related tables for Southwestern ponderosa pine. U. S. Forest Serv. Res. Pap. RM-2, 24 p. Rocky Mt. Forest and Range Exp. Stn., Fort Collins, Colo. 80521.

Presents volume tables, taper tables, and the distribution of tree volumes among the logs of saw log trees. Volumes are in total cubic feet and cubic feet to a variable top. Tree heights are in feet and numbers of logs.

Keywords: *Pinus ponderosa*, forest measurement, tree volume tables.

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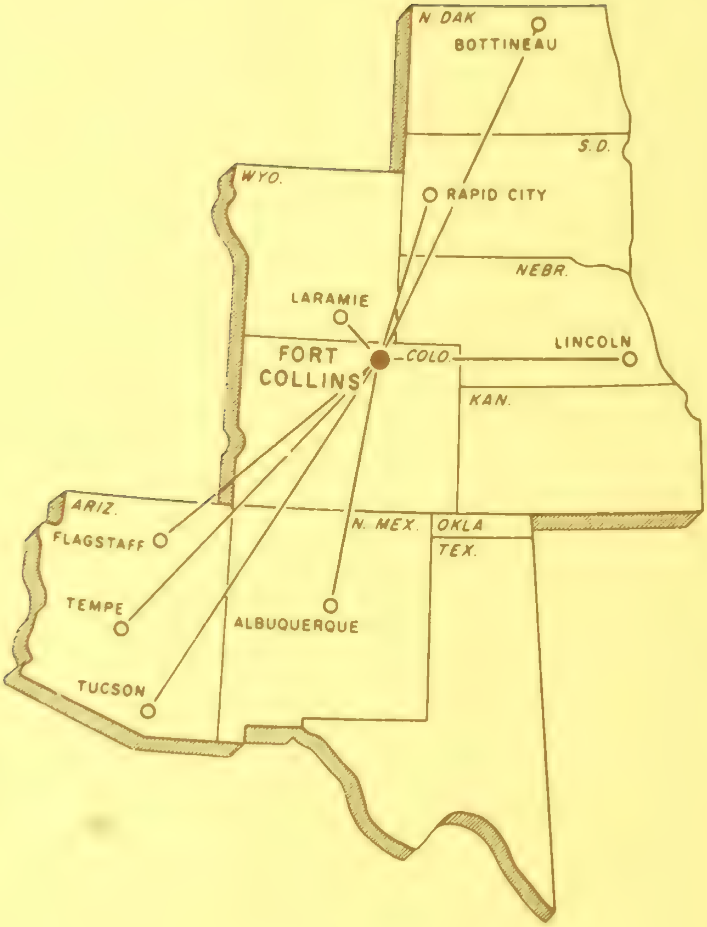
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Point-Sampling Factors for Southwestern Ponderosa Pine

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U. S. Forest Service Research Paper RM-3 October 1963

POINT-SAMPLING FACTORS
FOR
SOUTHWESTERN PONDEROSA PINE

by

Clifford A. Myers, Research Forester

Rocky Mountain Forest and Range Experiment Station [1]

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[1] Central headquarters maintained in cooperation with Colorado State University at Fort Collins.

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Point-Sampling Factors For Southwestern Ponderosa Pine

by

Clifford A. Myers

Volumes are computed from point-sample measurements of basal area by use of volume/basal area or point-sampling factors. Each factor is the number of cubic feet or board feet equivalent to 1 square foot of basal area. The factors presented here apply to ponderosa pine stands throughout Arizona and New Mexico. Volumes can be determined in merchantable cubic feet, board-feet International 1/4-inch rule, and board feet Scribner rule.

The techniques of point sampling have been described in numerous publications. A good discussion of the method was presented by Bonnett (1959). A simple procedure for determination of the number of sampling points (Allen and Mogren, 1960) and precautions on the use of point-sampling on small tracts (Afanasiev, 1958) have been published. Basic American references were prepared by Grosenbaugh (1952, 1955). Point-sampling techniques will not, therefore, be described here; this paper is limited to descriptions of the accompanying tables and instructions for their use.

DESCRIPTION OF TABLES

The first group of tables (1a to 5b) give point-sampling factors for each of numerous combinations of tree diameter and height. Volumes per square foot were obtained from the equations in the table footnotes. These equations resulted from the division of volume equations of the form $V = a + bD^2H$ (Myers, 1963) by $0.005454D^2$, a formula for basal area (B).

Tables 6a and 6b were derived from tables of the first group. The factor for each height class is the weighted average of the factors in that class given in the appropriate table of the first group. Weights were obtained from random samples of heights within diameter classes in all areas of commercial ponderosa pine in Arizona and New Mexico.

Unit of measure, stump height, and top diameter inside bark are given in the headings of tables 1a to 5b. Utilization of sawtimber was limited by variable top diameters inside bark, as follows:

Tree dbh (inches)	Minimum top sawlog diameter (inches)
12-13	8
14-21	9
22-26	10
27-31	11
32-35	12
36-39	13
40-42	14
43-45	15
46-47	16

These top diameters represent average full sawlog utilization of southwestern ponderosa pine.

Separate sets of factors are given for blackjack and old-growth ponderosa pines because their volume equations differ. Blackjack pines are immature or young mature trees with dark bark and relatively rapid taper. Old-growth pines have yellowish bark, often in broad flat plates, and less taper than blackjacks.

USE OF TABLES

Point-sample cruising for volume can be done in several ways. Diameters and heights of trees counted through the prism or relascope may be measured. Diameters may be estimated and heights measured. Heights of the counted trees may be measured and no record made of tree diameters. The procedure selected will depend on the accuracy desired and the time and personnel available for the job. Point-sampling factors are provided for each alternative.

Measurement of Diameter and Height

The diameter and height of each counted tree may be measured and a volume conversion factor selected for each combination of diameter and height (tables 1a to 5b). Volume per acre is computed as follows:

1. Multiply the number of counted trees in each diameter-height class by the point-sampling factor for the class.
2. Total the products of step one.
3. Multiply this total by the basal area factor of the prism or other angle gauge used.
4. Divide the product of step three by the number of points sampled on the tract.

Inspection of the tables shows that volume per square foot often does not differ greatly among trees of a single height class. For example, the volumes of blackjacks 80 feet tall vary from 27.3 to 29.9 cubic feet per square foot of basal area as diameter increases from 11 to 39 inches (table 1a). Board feet per square foot changes little with diameter when tree heights are measured in logs (tables 4a to 5b). Therefore, the increased time spent in the measurement of diameters may not result in any material increase in accuracy. Time can often be saved by the adoption of an alternative procedure. Heights of the counted trees can be measured while diameters are estimated and tallied by broad diameter classes. Or, heights can be measured and no record made of diameters.

Measurement Of Height Only

Measurement of heights only is recommended when volumes are to be determined in: (1) merchantable cubic feet or (2) in board feet if tree heights are measured in logs and stand structures are not highly irregular.

Point-sampling factors in tables 6a and 6b will be most useful where the distributions of diameters within height classes approximate those used in preparation of the tables. Differences in the relationship between height and diameter due to differences in site quality or stand density will change the factor for each height class. The changes will be small except for board feet with tree heights measured in feet.

If factors based on local conditions are desired, they may be obtained from tables 1a to 5b by almost the same procedure used to derive a local volume table from a standard table (Chapman and Meyer, 1949). The only difference is that diameters are plotted over heights instead of heights over diameters. This is because height will be retained as the measured variable.

Volumes are computed with the factors of tables 6a and 6b in the same way as when diameters are measured. The calculations will involve a maximum of 12 or 13 products of number of trees times factor for any one volume unit, instead of the many products computed when factors are selected for each combination of diameter and height.

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Table 1a.--Merchantable volume in cubic feet per square foot of basal area, blackjack ponderosa pine
Arizona and New Mexico

Cubic feet inside bark
Merchantable stem excluding stump and top

Top diameter 4.0 inches inside bark
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Total height in feet												
	20	30	40	50	60	70	80	90	100	110	120	130	140
	Cubic feet												
5	5.2	8.5	11.7	15.0									
6	5.6	8.8	12.1	15.3	18.6								
7	5.8	9.1	12.3	15.6	18.8								
8	6.0	9.2	12.5	15.7	19.0	22.2							
9	6.1	9.3	12.6	15.8	19.1	22.3							
10	6.1	9.4	12.6	15.9	19.2	23.0							
11	6.2	9.5	12.7	16.0	19.8	23.5	27.3						
12	6.2	9.5	12.7	16.4	20.2	24.0	27.7	31.5					
13		9.5	13.0	16.8	20.5	24.3	28.1	31.9					
14		9.6	13.3	17.1	20.8	24.6	28.4	32.1	35.9				
15		9.7	13.5	17.3	21.0	24.8	28.6	32.4	36.1				
16			13.7	17.5	21.2	25.0	28.8	32.5	36.3				
17			13.8	17.6	21.4	25.2	28.9	32.7	36.5	40.2			
18			14.0	17.7	21.5	25.3	29.1	32.8	36.6	40.4			
19			14.1	17.9	21.6	25.4	29.2	32.9	36.7	40.5			
20			14.2	17.9	21.7	25.5	29.3	33.0	36.8	40.6			
21				18.0	21.8	25.6	29.3	33.1	36.9	40.6			
22				18.1	21.9	25.6	29.4	33.2	37.0	40.7			
23				18.2	21.9	25.7	29.5	33.2	37.0	40.8	44.6		
24				18.2	22.0	25.8	29.5	33.3	37.1	40.8	44.6		
25					22.0	25.8	29.6	33.3	37.1	40.9	44.7	48.4	
26					22.1	25.8	29.6	33.4	37.2	40.9	44.7	48.5	52.2
27					22.1	25.9	29.7	33.4	37.2	41.0	44.7	48.5	52.3
28					22.2	25.9	29.7	33.5	37.2	41.0	44.8	48.5	52.3
29					22.2	26.0	29.7	33.5	37.3	41.0	44.8	48.6	52.3
30					22.2	26.0	29.8	33.5	37.3	41.1	44.8	48.6	52.4
31					22.2	26.0	29.8	33.5	37.3	41.1	44.9	48.6	52.4
32					22.3	26.0	29.8	33.6	37.3	41.1	44.9	48.6	52.4
33					22.3	26.1	29.8	33.6	37.4	41.1	44.9	48.7	52.4
34						26.1	29.8	33.6	37.4	41.1	44.9	48.7	52.5
35						26.1	29.9	33.6	37.4	41.2	44.9	48.7	52.5
36						26.1	29.9	33.6	37.4	41.2	45.0	48.7	52.5
37						26.1	29.9	33.7	37.4	41.2	45.0	48.7	52.5
38						26.1	29.9	33.7	37.4	41.2	45.0	48.8	52.5
39							29.9	33.7	37.5	41.2	45.0	48.8	52.5
40								33.7	37.5	41.2	45.0	48.8	52.5
41								33.7	37.5	41.2	45.0	48.8	52.6
42								33.7	37.5	41.3	45.0	48.8	52.6
43								33.7	37.5	41.3	45.0	48.8	52.6

Derived from: $V/B = 0.32453\ H - 37.6788/D^2$, above dotted line.

$V/B = 0.37697\ H - 377.9752/D^2$, below dotted line.

Diameter classes full-inch; e.g. 20-inch class includes 20.0 to 20.9.

Table 1b.--Merchantable volume in cubic feet per square foot of basal area, old-growth ponderosa pine
Arizona and New Mexico

Cubic feet inside bark
Merchantable stem excluding stump and top

Top diameter 4.0 inches inside bark
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Total height in feet										
	40	50	60	70	80	90	100	110	120	130	140
	Cubic feet										
12	14.8	19.0	23.1	27.3	31.4	35.5	39.7				
13	15.1	19.2	23.4	27.5	31.6	35.8	39.9				
14	15.3	19.4	23.6	27.7	31.8	36.0	40.1				
15	15.4	19.6	23.7	27.8	32.0	36.1	40.2				
16	15.6	19.7	23.8	28.0	32.1	36.2	40.4				
17	15.7	19.8	23.9	28.1	32.2	36.3	40.5	44.6			
18	15.8	19.9	24.0	28.2	32.3	36.4	40.6	44.7			
19	15.8	20.0	24.1	28.2	32.4	36.5	40.7	44.8	48.9		
20		20.0	24.2	28.3	32.4	36.6	40.7	44.9	49.0		
21		20.1	24.2	28.4	32.5	36.6	40.8	44.9	49.0	53.2	
22		20.2	24.3	28.4	32.6	36.7	40.8	45.0	49.1	53.2	
23		20.2	24.3	28.5	32.6	36.7	40.9	45.0	49.1	53.3	
24			24.4	28.5	32.6	36.8	40.9	45.0	49.2	53.3	
25			24.4	28.5	32.7	36.8	40.9	45.1	49.2	53.3	
26			24.4	28.6	32.7	36.8	41.0	45.1	49.2	53.4	
27			24.5	28.6	32.7	36.9	41.0	45.1	49.3	53.4	
28			24.5	28.6	32.8	36.9	41.0	45.2	49.3	53.4	57.6
29			24.5	28.6	32.8	36.9	41.0	45.2	49.3	53.4	57.6
30			24.5	28.7	32.8	36.9	41.1	45.2	49.3	53.5	57.6
31			24.5	28.7	32.8	36.9	41.1	45.2	49.3	53.5	57.6
32				28.7	32.8	37.0	41.1	45.2	49.4	53.5	57.6
33				28.7	32.8	37.0	41.1	45.2	49.4	53.5	57.6
34				28.7	32.9	37.0	41.1	45.3	49.4	53.5	57.7
35				28.7	32.9	37.0	41.1	45.3	49.4	53.5	57.7
36				28.7	32.9	37.0	41.1	45.3	49.4	53.6	57.7
37				28.8	32.9	37.0	41.2	45.3	49.4	53.6	57.7
38				28.8	32.9	37.0	41.2	45.3	49.4	53.6	57.7
39				28.8	32.9	37.0	41.2	45.3	49.4	53.6	57.7
40					32.9	37.1	41.2	45.3	49.5	53.6	57.7
41					32.9	37.1	41.2	45.3	49.5	53.6	57.7
42						37.1	41.2	45.3	49.5	53.6	57.7
43						37.1	41.2	45.3	49.5	53.6	57.7
44						37.1	41.2	45.3	49.5	53.6	57 8
45						37.1	41.2	45.4	49.5	53.6	57.8
46						37.1	41.2	45.4	49.5	53.6	57.8
47							41.2	45.4	49.5	53.6	57.8

Derived from: $V/B = 0.41346\,H - 264.1790/D^2$

Diameter classes full-inch; e.g. 20-inch class includes 20.0 to 20.9.

Table 2a.--Volume in board feet Scribner rule per square foot of basal area, blackjack ponderosa pine
Arizona and New Mexico

Board feet inside bark
Merchantable stem excluding stump and top

Top diameter variable
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Total height in feet											
	30	40	50	60	70	80	90	100	110	120	130	140
	Board feet											
12	21	38	56	73	91	108	125					
13	26	43	60	78	95	112	130					
14	29	46	64	81	99	116	133	155				
15	32	49	67	84	101	119	142	167				
16		52	69	86	104	127	152	177				
17		54	71	88	110	135	161	186	211			
18		55	73	91	117	142	168	193	219			
19		57	74	98	123	148	174	199	225			
20			77	103	128	154	179	205	230			
21			82	107	133	158	184	209	235			
22			86	111	137	162	188	213	239			
23			89	115	140	166	191	217	242	267		
24			92	118	143	169	194	220	245	271		
25				120	146	171	197	222	248	273	299	
26				123	148	174	199	225	250	276	301	327
27				125	150	176	201	227	252	278	303	329
28				127	152	178	203	229	254	280	305	331
29				129	154	180	205	230	256	281	307	332
30				130	156	181	207	232	257	283	308	334
31				132	157	183	208	233	259	284	310	335
32				133	158	184	209	235	260	286	311	337
33				134	160	185	210	236	261	287	312	338
34					161	186	212	237	262	288	313	339
35					162	187	212	238	263	289	314	340
36					162	188	213	239	264	290	315	341
37					163	189	214	240	265	291	316	342
38					164	190	215	240	266	291	317	342
39						190	216	241	267	292	318	343
40							216	242	267	293	318	344
41							217	242	268	293	319	344
42							218	243	268	294	319	345
43							218	244	269	294	320	345

Derived from: $V/B = 1.7384\ H - 4855.5739/D^2$, above dotted line.

$V/B = 2.5462\ H - 21011.4393/D^2$, below dotted line.

Diameter classes full-inch; e.g. 20-inch class includes 20.0 to 20.9.

Table 2b.--Volume in board feet Scribner rule per square foot of basal area, old-growth ponderosa pine
Arizona and New Mexico

Board feet inside bark
Merchantable stem excluding stump and top

Top diameter variable
Stump height 1.0 feet

Diameter breast height outside bark (Inches)	Total height in feet										
	40	50	60	70	80	90	100	110	120	130	140
	Board feet										
12	36	58	80	102	124	146	168				
13	43	65	87	109	131	153	175				
14	49	71	93	115	137	159	181				
15	54	76	98	120	142	164	188				
16	58	80	102	124	146	171	200				
17	61	83	105	127	152	181	210	238			
18	64	86	108	132	160	189	218	246			
19	66	88	110	139	167	196	225	253	282		
20		90	116	144	173	202	231	259	288	317	
21		92	121	150	178	207	236	265	293	322	
22		97	125	154	183	212	240	269	298	326	
23		101	129	158	187	215	244	273	302	330	
24			133	161	190	219	248	276	305	334	
25			136	165	193	222	251	279	308	337	
26			138	167	196	225	253	282	311	340	
27			141	170	198	227	256	285	313	342	
28			143	172	201	229	258	287	315	344	373
29			145	174	202	231	260	289	317	346	375
30			147	176	204	233	262	290	319	348	377
31			148	177	206	235	263	292	321	349	378
32				179	207	236	265	293	322	351	380
33				180	209	237	266	295	324	352	381
34				181	210	239	267	296	325	353	382
35				182	211	240	268	297	326	355	383
36				183	212	241	269	298	327	356	384
37				184	213	242	270	299	328	357	385
38				185	214	242	271	300	329	357	386
39				186	215	243	272	301	329	358	387
40					215	244	273	301	330	359	388
41					216	245	273	302	331	360	388
42						245	274	303	332	360	389
43						246	275	303	332	361	390
44						247	275	304	333	361	390
45						247	276	304	333	362	391
46						248	276	305	334	362	391
47							277	305	334	363	392

Derived from: $V/B = 2.1933\ H - 8090.5757/D^2$, above dotted line.
$V/B = 2.8724\ H - 23775.6656/D^2$, below dotted line.

Diameter classes full-inch; e.g. 20-inch class includes 20.0 to 20.9.

Table 3a.--Volume in board feet International ¼-inch rule per square foot of basal area, blackjack ponderosa pine
Arizona and New Mexico

Board feet inside bark
Merchantable stem excluding stump and top

Top diameter variable
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Total height in feet											
	30	40	50	60	70	80	90	100	110	120	130	140
	Board feet											
12	21	42	64	85	107	128	150					
13	27	48	70	91	113	135	156					
14	32	53	75	97	118	140	161	185				
15	36	58	79	101	122	144	168	194				
16		61	82	104	125	150	176	202				
17		64	85	107	130	157	183	209	235			
18		66	88	110	136	162	188	215	241			
19		68	90	115	141	167	193	219	245			
20			92	119	145	171	197	223	249			
21			96	122	148	174	201	227	253			
22			99	125	151	177	204	230	256			
23			102	128	154	180	206	232	259	285		
24			104	130	156	182	209	235	261	287		
25				132	158	185	211	237	263	289	315	
26				134	160	186	213	239	265	291	317	343
27				136	162	188	214	240	266	293	319	345
28				137	163	189	216	242	268	294	320	346
29				138	165	191	217	243	269	295	322	348
30				140	166	192	218	244	270	297	323	349
31				141	167	193	219	245	272	298	324	350
32				142	168	194	220	246	273	299	325	351
33				143	169	195	221	247	273	300	326	352
34					170	196	222	248	274	300	327	353
35					170	197	223	249	275	301	327	353
36					171	197	223	250	276	302	328	354
37					172	198	224	250	276	302	329	355
38					172	198	225	251	277	303	329	355
39						199	225	251	277	304	330	356
40							226	252	278	304	330	356
41							226	252	278	305	331	357
42							227	253	279	305	331	357
43							227	253	279	305	332	358

Derived from: $V/B = 2.1533\ H - 6870.6637/D^2$, above dotted line.

$V/B = 2.6164\ H - 16133.6238/D^2$, below dotted line.

Diameter classes full-inch; e.g. 20-inch class includes 20.0 to 20.9.

Table 3b.--Volume in board feet International ½-inch rule per square foot of basal area, old-growth ponderosa pine
Arizona and New Mexico

Board feet inside bark
Merchantable stem excluding stump and top

Top diameter variable
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Total height in feet										
	40	50	60	70	80	90	100	110	120	130	140
	Board feet										
12	46	72	98	123	149	175	200				
13	54	80	106	131	157	183	208				
14	61	86	112	138	163	189	215				
15	66	92	117	143	169	194	222				
16	70	96	122	147	173	201	230				
17	74	100	125	151	178	208	237	267			
18	77	103	128	155	184	214	243	273			
19	80	105	131	160	189	219	248	278	307		
20		107	135	164	194	223	253	282	311	341	
21		109	139	168	198	227	256	286	315	345	
22		113	142	171	201	230	260	289	319	348	
23		116	145	174	204	233	263	292	321	351	
24			147	177	206	236	265	295	324	353	
25			150	179	209	238	267	297	326	356	
26			152	181	210	240	269	299	328	358	
27			153	183	212	242	271	300	330	359	
28			155	184	214	243	273	302	331	361	390
29			156	186	215	245	274	304	333	362	392
30			158	187	217	246	275	305	334	364	393
31			159	188	218	247	277	306	335	365	394
32				189	219	248	278	307	336	366	395
33				190	220	249	279	308	337	367	396
34				191	221	250	279	309	338	368	397
35				192	221	251	280	310	339	369	398
36				193	222	252	281	310	340	369	399
37				193	223	252	282	311	341	370	399
38				194	224	253	282	312	341	371	400
39				195	224	254	283	312	342	371	401
40					225	254	283	313	342	372	401
41					225	255	284	313	343	372	402
42						255	284	314	343	373	402
43						255	285	314	344	373	403
44						256	285	315	344	374	403
45						256	286	315	345	374	403
46						257	286	315	345	374	404
47							286	316	345	375	404

Derived from: $V/B = 2.5669\ H - 8800.8801/D^2$, above dotted line.
$V/B = 2.9411\ H - 17420.8616/D^2$, below dotted line.

Diameter classes full-inch; e.g. 20-inch class includes 20.0 to 20.9.

Table 4a.--Volume in board feet Scribner rule per square foot of basal area, blackjack ponderosa pine
Arizona and New Mexico

Board feet inside bark
Merchantable stem excluding stump and top

Top diameter variable
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Number of merchantable 16-foot logs												
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0
	Board feet												
12	51	71	92	113	133								
13	49	70	91	111	132	152							
14	48	69	90	110	131	151							
15	47	68	89	109	130	153	180						
16	47	67	88	109	130	157	185	213					
17	46	67	87	108	134	161	189	216					
18		66	87	110	137	165	192	220	247				
19		66	86	112	140	167	195	222	250				
20		65	87	115	142	170	197	225	252				
21		65	89	117	144	172	199	227	254				
22		65	91	119	146	174	201	229	256				
23		65	93	120	148	175	203	230	258	285			
24		67	94	122	149	177	204	232	259	287			
25			95	123	150	178	205	233	260	288	315		
26				124	151	179	206	234	262	289	317	344	
27				125	152	180	207	235	262	290	317	345	
28				126	153	181	208	236	263	291	318	346	
29				127	154	182	209	237	264	292	319	347	374
30				127	155	182	210	237	265	292	320	347	375
31				128	155	183	210	238	265	293	320	348	376
32				129	156	184	211	239	266	294	321	349	376
33				129	157	184	212	239	267	294	322	349	377
34				130	157	185	212	240	267	295	322	350	377
35				130	157	185	213	240	268	295	323	350	378
36					158	185	213	240	268	295	323	350	378
37					158	186	213	241	268	296	323	351	378
38					159	186	214	241	269	296	324	351	379
39						186	214	241	269	296	324	352	379
40							214	242	269	297	324	352	379
41							215	242	270	297	325	352	380
42							215	242	270	297	325	352	380
43							215	243	270	298	325	353	380

Derived from: $V/B = 41.2162\ H + 1497.1764/D^2$, above dotted line.

$V/B = 55.0204\ H - 9550.8089/D^2$, below dotted line.

Diameter classes full-inch; e.g. 20-inch class includes 20.0 to 20.9.

Table 4b.--Volume in board feet Scribner rule per square foot of basal area, old-growth ponderosa pine
Arizona and New Mexico

Board feet inside bark
Merchantable stem excluding stump and top

Top diameter variable
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Number of merchantable 16-foot logs												
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0
	Board feet												
12	45	70	95	120	146	171							
13	45	71	96	121	147	172	197						
14	46	71	97	122	147	173	198						
15	47	72	97	123	148	173	198	224					
16	47	72	98	123	148	174	199	227					
17	48	73	98	123	149	174	202	232					
18		73	98	124	149	176	206	236	266				
19		73	99	124	149	179	209	239	269	299			
20		74	99	124	152	182	212	242	272	302	332		
21		74	95	125	155	185	214	244	274	304	334	364	
22			97	127	157	187	217	247	276	306	336	366	
23				129	159	189	218	248	278	308	338	368	
24				130	160	190	220	250	280	310	340	370	
25				132	162	192	222	252	282	311	341	371	
26				133	163	193	223	253	283	313	343	373	
27				134	164	194	224	254	284	314	344	374	
28				135	165	195	225	255	285	315	345	375	
29				136	166	196	226	256	286	316	346	376	
30				137	167	197	227	257	287	317	347	377	407
31				138	168	198	228	258	288	318	347	377	407
32				139	169	199	228	258	288	318	348	378	408
33					169	199	229	259	289	319	349	379	409
34					170	200	230	260	290	319	349	379	409
35					170	200	230	260	290	320	350	380	410
36					171	201	231	261	291	321	350	380	410
37					171	201	231	261	291	321	351	381	411
38						202	232	262	291	321	351	381	411
39						202	232	262	292	322	352	382	412
40						202	232	262	292	322	352	382	412
41						203	233	263	293	322	352	382	412
42							233	263	293	323	353	383	413
43							233	263	293	323	353	383	413
44							234	263	293	323	353	383	413
45							234	264	294	324	354	383	413
46							234	264	294	324	354	384	414
47								264	294	324	354	384	414

Derived from: $V/B = 50.5655\ H - 933.4892/D^2$, above dotted line.
$V/B = 59.8509\ H - 11544.2484/D^2$, below dotted line.

Diameter classes full-inch; e.g. 20-inch class includes 20.0 to 20.9.

Table 5a.--Volume in board feet International ¼-inch rule per square foot of basal area, blackjack ponderosa pine
Arizona and New Mexico

Board feet inside bark
Merchantable stem excluding stump and top

Top diameter variable
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Number of merchantable 16-foot logs												
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0
	Board feet												
12	62	86	110	134	158								
13	60	84	108	132	156	180							
14	58	82	106	130	154	177							
15	57	81	105	129	151	180	208						
16	56	80	104	128	154	182	210	238					
17	55	79	103	127	155	184	212	240					
18		78	102	129	157	185	213	242	270				
19		78	102	130	158	186	215	243	271				
20		77	103	131	159	187	216	244	272				
21		77	104	132	160	188	217	245	273				
22		76	104	133	161	189	218	246	274				
23		77	105	133	162	190	218	247	275	303			
24		78	106	134	162	191	219	247	275	304			
25			106	135	163	191	219	248	276	304	333		
26				135	163	192	220	248	276	305	333	361	
27				136	164	192	220	249	277	305	333	362	
28				136	164	193	221	249	277	306	334	362	
29				136	165	193	221	249	278	306	334	363	391
30				137	165	193	221	250	278	306	335	363	391
31				137	165	194	222	250	278	307	335	363	391
32				137	165	194	222	250	279	307	335	363	392
33				137	166	194	222	251	279	307	335	364	392
34				138	166	194	223	251	279	307	336	364	392
35				138	166	194	223	251	279	308	336	364	392
36					166	195	223	251	279	308	336	364	393
37					167	195	223	251	280	308	336	364	393
38					167	195	223	252	280	308	336	365	393
39						195	223	252	280	308	336	365	393
40							224	252	280	308	337	365	393
41							224	252	280	308	337	365	393
42							224	252	280	309	337	365	393
43							224	252	280	309	337	365	394

Derived from: $V/B = 47.7723\ H + 2257.4716/D^2$, above dotted line.
$V/B = 56.5466\ H - 4377.0735/D^2$, below dotted line.

Diameter classes full-inch; e.g. 20-inch class includes 20.0 to 20.9.

Table 5b.--Volume in board feet International ¼-inch rule per square foot of basal area, old growth ponderosa pine
Arizona and New Mexico

Board feet inside bark
Merchantable stem excluding stump and top

Top diameter variable
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Number of merchantable 16-foot logs												
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0
	Board feet												
12	56	86	115	145	174	203							
13	57	86	116	145	174	204	233						
14	57	86	116	145	175	204	233						
15	57	87	116	145	175	204	234	263					
16	57	87	116	146	175	204	234	263					
17	58	87	116	146	175	205	234	263					
18		87	117	146	175	205	234	260	290				
19		87	117	146	175	205	231	261	292	323			
20		87	117	146	176	201	232	263	293	324	355		
21		87	117	146	176	203	233	264	295	325	356	387	
22			117	146	173	204	234	265	296	326	357	388	
23				146	174	205	235	266	297	327	358	388	
24				144	175	205	236	267	297	328	359	389	
25				145	175	206	237	267	298	329	359	390	
26				145	176	207	237	268	299	329	360	391	
27				146	177	207	238	269	299	330	361	391	
28				146	177	208	238	269	300	330	361	392	
29				147	178	208	239	270	300	331	361	392	
30				147	178	209	239	270	301	331	362	393	423
31				148	178	209	240	270	301	332	362	393	424
32				148	179	209	240	271	301	332	363	393	424
33					179	210	240	271	302	332	363	394	424
34					179	210	241	271	302	333	363	394	424
35					180	210	241	271	302	333	363	394	425
36					180	210	241	272	302	333	364	394	425
37					180	211	241	272	303	333	364	395	425
38						211	241	272	303	333	364	395	425
39						211	242	272	303	334	364	395	426
40						211	242	272	303	334	364	395	426
41						211	242	273	303	334	365	395	426
42							242	273	303	334	365	395	426
43							242	273	304	334	365	396	426
44							242	273	304	334	365	396	426
45							243	273	304	334	365	396	426
46							243	273	304	335	365	396	427
47								273	304	335	365	396	427

Derived from: $V/B = 58.8214\ H - 389.9661/D^2$, above dotted line.

$V/B = 61.3012\ H - 5523.7105/D^2$, below dotted line.

Diameter classes full-inch; e.g. 20-inch class includes 20.0 to 20.9.

Table 6a.--Tree volumes per square foot of basal area by tree heights, blackjack and old-growth ponderosa pines (measured in feet)

Tree height (feet)	Blackjacks			Old-growth		
	Merchantable cubic feet	Board feet Scribner	Board feet International	Merchantable cubic feet	Board feet Scribner	Board feet International
20	5.3	--	--	--	--	--
30	9.0	21	26	11.0	--	--
40	12.6	41	50	15.3	44	55
50	16.5	63	74	19.5	70	84
60	20.9	86	102	23.8	101	120
70	25.1	117	135	28.2	138	160
80	29.3	156	171	32.4	178	199
90	33.2	194	208	36.7	218	234
100	37.2	230	242	40.9	255	272
110	41.1	258	271	45.2	290	305
120	45.0	286	300	49.4	324	338
130	48.7	311	325	53.6	354	368
140	52.4	336	350	57.7	384	398

Table 6b.--Tree volumes per square foot of basal area by tree heights, blackjack and old-growth ponderosa pines (measured in logs)

Tree height logs	Blackjacks		Old-growth	
	Board feet Scribner	Board feet International	Board feet Scribner	Board feet International
1.0	50	60	45	57
1.5	69	83	71	86
2.0	89	106	97	116
2.5	112	130	123	146
3.0	142	158	154	176
3.5	176	190	186	206
4.0	206	220	224	237
4.5	236	249	255	269
5.0	265	278	286	301
5.5	293	307	318	332
6.0	321	336	349	364
6.5	350	365	380	395
7.0	378	393	411	426

Myers, Clifford A.
1963. Point-sampling factors for southwestern ponderosa pine.
U. S. Forest Serv. Res. Paper RM-3, 15 pp., illus.
Rocky Mountain Forest and Range Experiment Station,
Fort Collins, Colorado.

Presents factors for cubic feet to a 4.0-inch top, board feet Scribner rule to a variable top, and board feet International 1/4-inch rule to a variable top. Tree heights are in feet and numbers of logs, with and without subdivision by diameter classes.

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Habitat Relations of Vertebrates

of the

Sierra Ancha Experimental Forest

Hudson G. Reynolds
R. Roy Johnson

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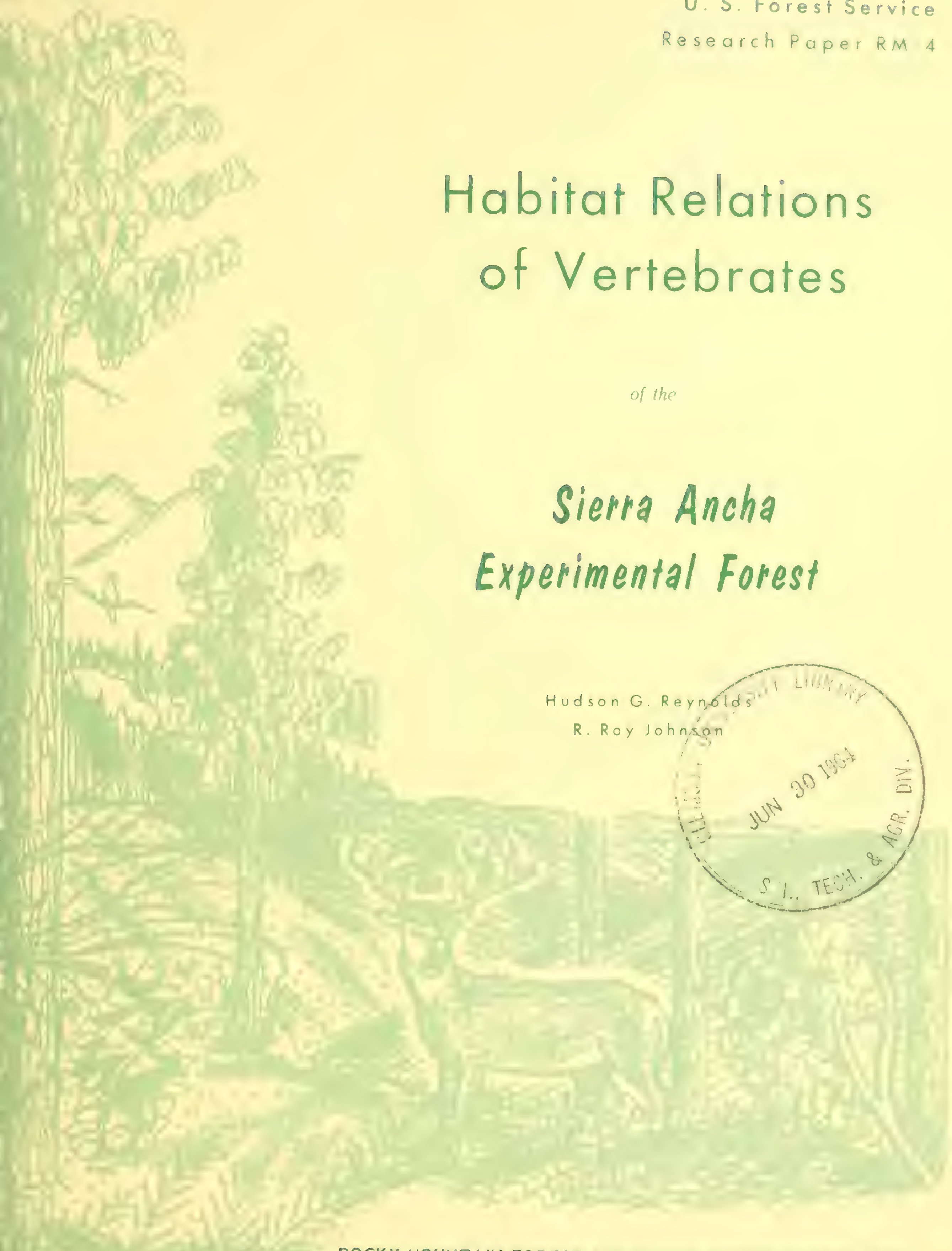

ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION
RAYMOND PRICE, DIRECTOR FORT COLLINS, COLORADO
FOREST SERVICE U. S. DEPARTMENT OF AGRICULTURE

U. S. Forest Service Research Paper RM-4 March 1964

HABITAT RELATIONS OF VERTEBRATES OF THE SIERRA ANCHA EXPERIMENTAL FOREST[1]

by

Hudson G. Reynolds, Wildlife Research Biologist[2]

and

R. Roy Johnson, Graduate Student[3]

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[1] A portion of the Tonto National Forest, set aside for experimental purposes in 1932, under authority of the Secretary of the U. S. Department of Agriculture, and administered by the Rocky Mountain Forest and Range Experiment Station.

[2] Rocky Mountain Forest and Range Experiment Station, with central headquarters maintained in cooperation with Colorado State University at Fort Collins; author is stationed at Tempe in cooperation with Arizona State University.

[3] Department of Zoology, University of Arizona, Tucson.

Habitat Relations of Vertebrates of the Sierra Ancha Experimental Forest

by
Hudson G. Reynolds and R. Roy Johnson

Many forms of vertebrates are found on the 14,000-acre Sierra Ancha Experimental Forest of the Sierra Ancha Mountains, which lie between Globe and Young, Gila County, Arizona. Elevations range from 3,500 feet to over 7,000 feet; soils and aspects vary greatly. As a result, vegetation associations are complex. Such varied environmental conditions produce a diversity of habitats for vertebrates.

This paper describes the Experimental Forest in general terms, characterizes the more important vertebrate habitats, and presents a checklist of vertebrates together with notes as to relative abundance, seasonal occurrence, and macro- and microhabitats.

For nearly 30 years, precipitation and runoff have been measured from numerous watersheds within the Experimental Forest. Vegetation has been modified on some watersheds to determine the influences of different kinds, statures, and arrangements of vegetation upon water yields and erosion. Other experimental watersheds have been grazed or logged.

Past or future changes in plant cover may have or may be expected to affect the vertebrate fauna. Some species could be favored; others affected adversely. Multiple-use land management is concerned with the interrelated effects of land use upon both fauna and flora. Hence, an inventory of vertebrate fauna in relation to their habitats provides important basic information. Moreover, as vegetation is changed by various experiments, responses of vertebrate animals can be related to habitat modifications. From such data, the impact of land-management activities involving modification of vegetation upon vertebrate fauna can be predicted.

HABITATS

Macrohabitats are designated according to dominant vegetation as pine-fir, ponderosa pine, chaparral, and desert grassland. Microhabitats or vertebrate niches exist within macrohabitats. These niches have both space and stature relations to macrohabitats. Macrohabitats are always given for each vertebrate; where relations are known, microhabitats are also identified.

Pine-Fir

The pine-fir habitat is found at the highest elevations on the Forest--from 6,000 to over 7,000 feet (fig. 1). Best development of trees is reached under comparatively cool and moist conditions of north- and east-facing slopes. Dominant trees include Douglas-fir,[4] white fir, and ponderosa pine. Understory associated trees are Gambel oak, and New-Mexican locust. Where light penetrates the canopy, mountain snowberry is common.

Important microhabitats include (1) rocky cliffs, (2) natural forest openings, (3) forest clearings, (4) alder-maple riparian sites, (5) aspen, and (6) numerous situations associated with stature and foliage of trees (fig. 2). Natural forest openings are dominated by Kentucky bluegrass, although numerous forbs are also present. Introduced orchardgrass dominates forest clearings. Riparian sites have a dominant overstory of bigtooth maple, boxelder, and Arizona alder. Common monkeyflower and golden columbine are common

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[4] For common and botanical names of plants mentioned, see page 7.

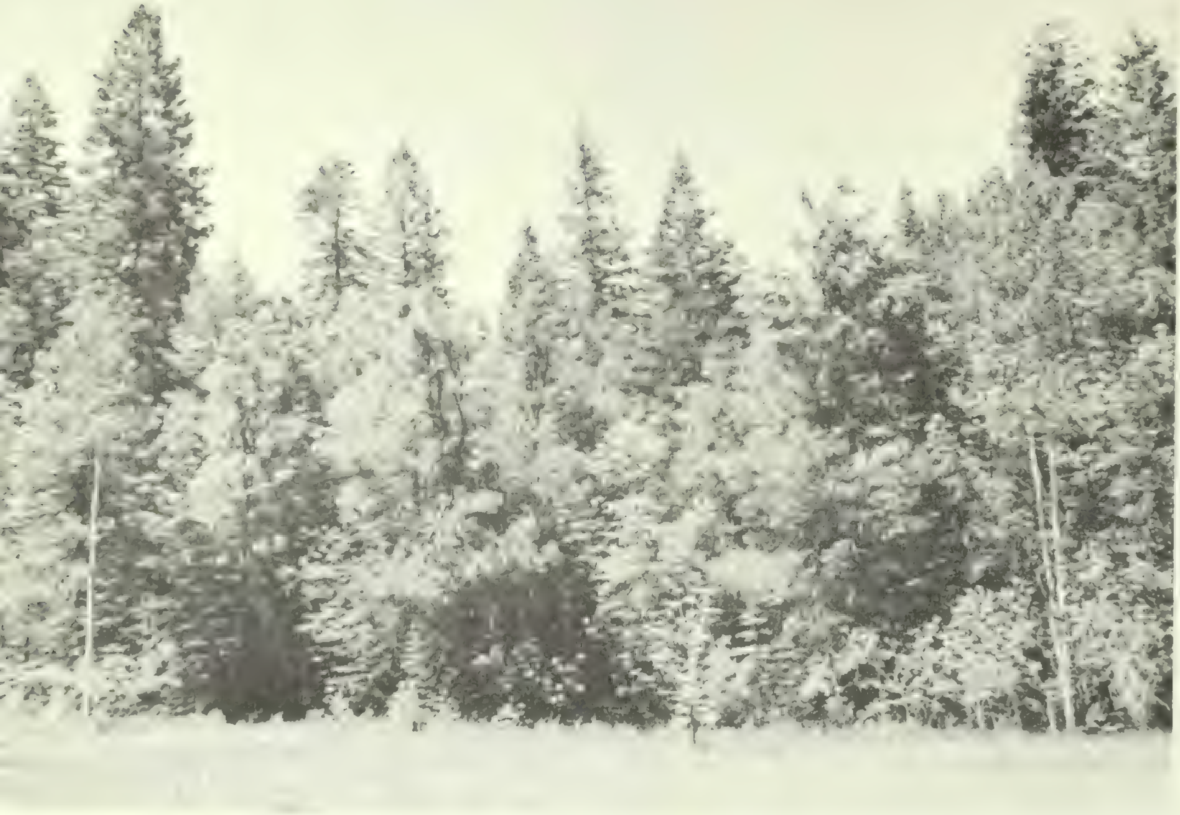
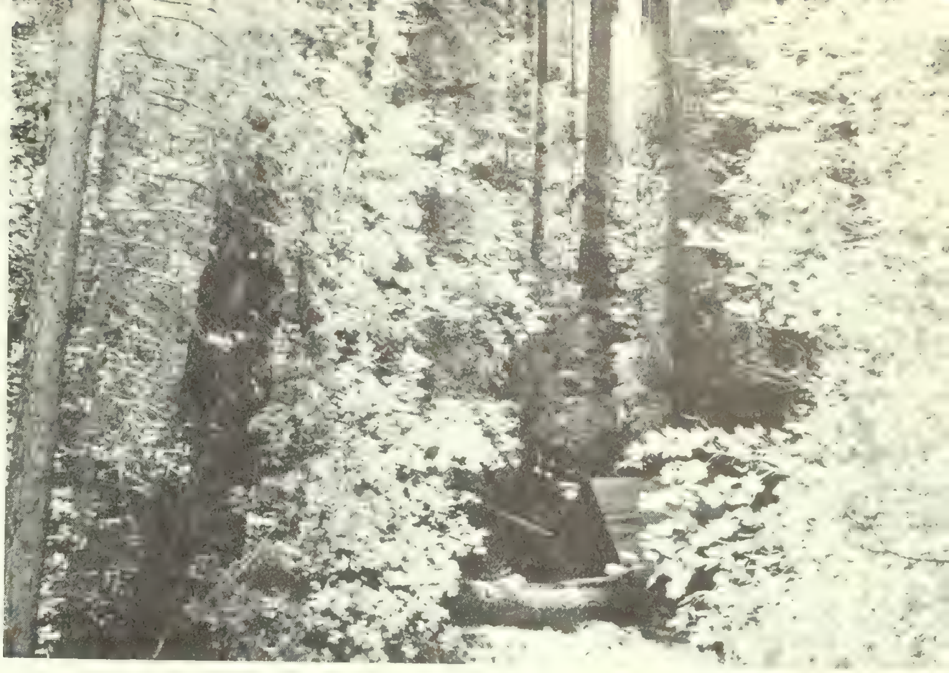


Figure 1.--In the pine-fir habitat, the overstory of Douglas-fir, white fir, and ponderosa pine is dense, but the understory vegetation is scanty.

Figure 2.--Typical of some of the microhabitats found on the Sierra Ancha Experimental forest are:

Alder-maple riparian



Natural forest openings with rocky cliffs in background.

Oak-sycamore riparian

where permanent water exists. Aspen sites are overstoried by quaking aspen; they may be understoried by white fir reproduction and mountain snowberry. Numerous forbs are usually present.

Representative vertebrates include the Mexican packrat,[5] porcupine, sharp-shinned hawk, turkey, hairy woodpecker, and Coues' flycatcher. In riparian situations, the red-faced warbler is characteristic.

Ponderosa Pine

The ponderosa pine habitat extends from 7,000 feet down to about 5,500 feet elevation (fig. 3). At the higher elevations, the habitat is found on drier sites--south- and west-facing slopes and shallow soils.

Ponderosa pine is the dominant tree. Associated trees in the understory include Gambel oak, New-Mexican locust, and emory oak. Bracken is the most conspicuous herbaceous plant. There are minor amounts of blue grama and prairie Junegrass.

Flora of microhabitats of rocky cliffs, natural forest openings, and forest clearings is similar to that of the pine-fir habitat. In addition, emory oak and oak-sycamore microhabitats are found in ponderosa pine. Emory oak environments are confined to drier situations of shallow soils, south-facing aspects, rock outcrops, or combinations thereof. Associated shrubs in the understory include birchleaf mountainmahogany and pointleaf manzanita. Oak-sycamore riparian sites are characterized by Arizona white oak, Arizona sycamore, and Arizona walnut.

Among the conspicuous vertebrates are tassel-eared squirrel, whitetail deer, Steller's jay, western bluebird, and chipping sparrow. Vertebrates often seen in the oak-sycamore microhabitat are Arizona gray squirrel, Cooper's hawk, screech owl, western and Cassin's kingbirds, and bridled titmouse.

Chaparral

The chaparral habitat occupies elevations from about 4,000 to 6,000 feet (fig. 4). Among the most conspicuous woody species are shrub live oak, skunkbush sumac, pointleaf manzanita, hollyleaf buckthorn, desert ceanothus, Wright silktassel, and birchleaf mountainmahogany. The most prominent perennial grasses in the understory are side-oats grama and hairy grama.

The main microhabitats include rocky cliffs and oak-sycamore riparian sites that have been previously described.

Among the more conspicuous vertebrates encountered in this habitat are the banded gecko, scrub jay, plain titmouse, western rooter skunk, and ringtail.

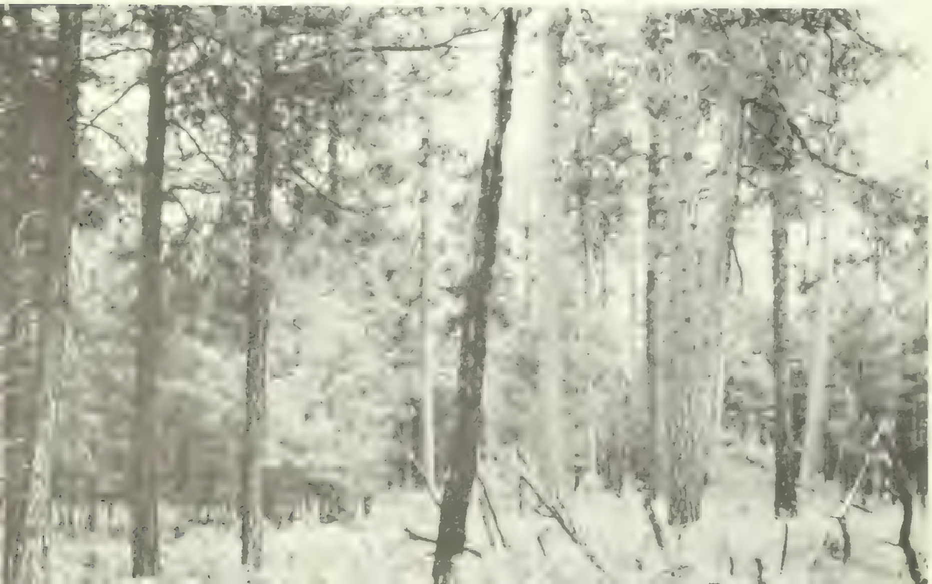


Figure 3.--Dense understory grows in the ponderosa pine habitat where the overstory of trees is open.

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[5] For scientific names, see checklist beginning on page 9.

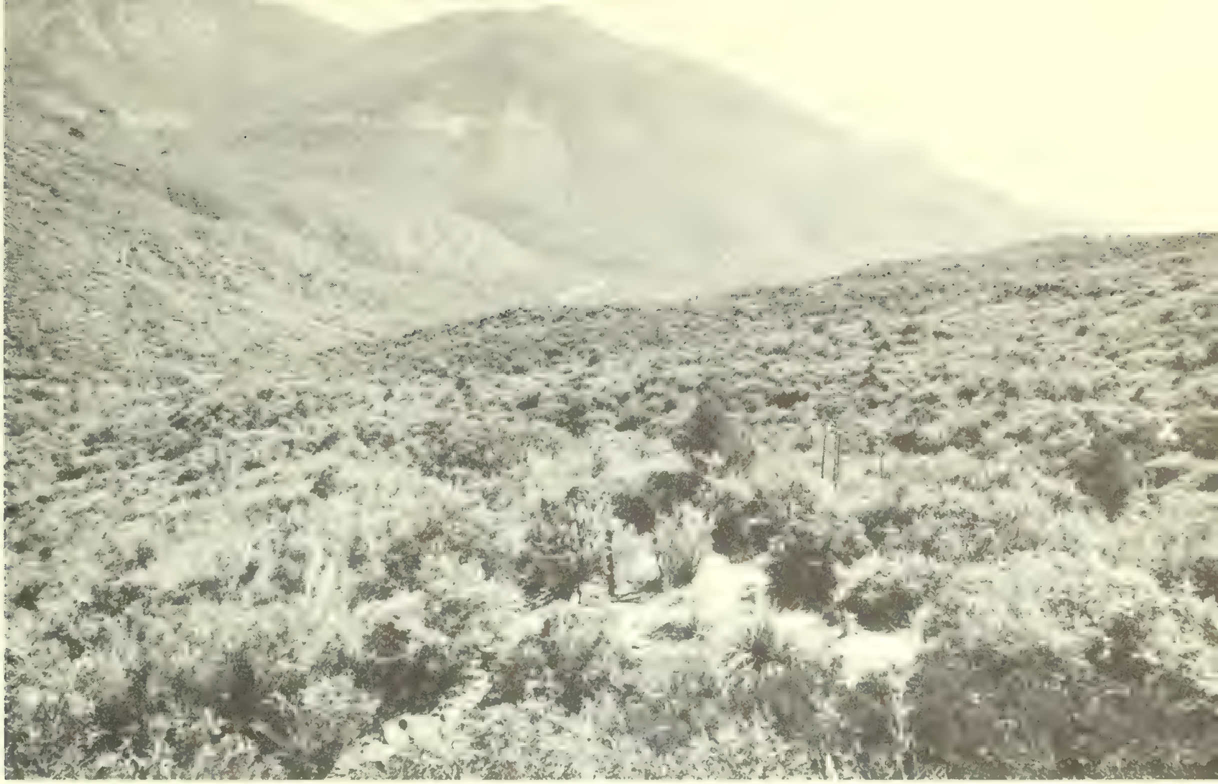

Figure 4.--In this chaparral habitat, the shrub canopy is fairly open and a good understory cover grows.

Desert Grassland

The desert grassland habitat is comparatively small on the Experimental Forest (fig. 5). This environment is confined to benchlands below 5,000 feet elevation where soils are comparatively shallow. There is some invasion of velvet mesquite. The most abundant halfshrub is broom snakeweed. Common perennial grasses include side-oats grama, hairy grama, black grama, and curlymesquite.

The most characteristic vertebrates of this habitat include the Gila monster, Gambel's quail, roadrunner, mockingbird, phainopepla, and peccary.

COLLECTIONS AND IDENTIFICATIONS

Many of the species collections and identifications were made by the junior author in preparing a Master's thesis for the Department of Zoology at the University of Arizona, Tucson.[6] Other identifications are from previous museum collections. Data on reptiles and amphibians are from a collection by Little.[7]

In the "Checklist of Vertebrates and Habitat Relations" which follows, scientific and common names of birds are according to the AOU;[8] other vertebrates, Blair et al.[9]

Museum collections and sight identifications are indicated by the following symbols:

USNM --	United States National Museum, Washington, D.C.
MVZ --	Museum of Vertebrate Zoology, University of California, Berkeley, California
UA --	University of Arizona, Tucson, Arizona
JSW --	Johnson-Simpson-Werner Collection, Arizona State University, Tempe, Arizona
Sight --	Sight record only

The relative abundance of each species is indicated as follows:

Abundant --	The species is conspicuous and is easily collected, or may be observed several times in passing through a major habitat
Common --	The species can be located any time during the proper season by working carefully in a specific habitat

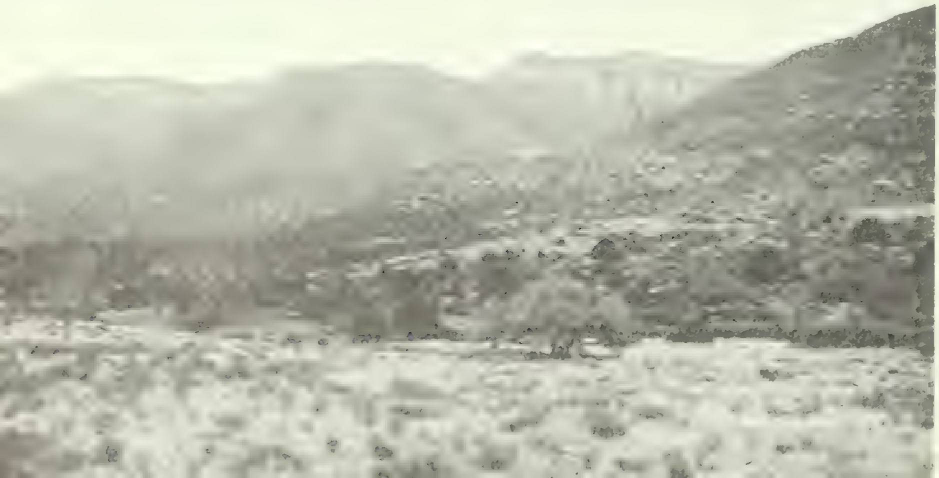

Figure 5.--Velvet mesquite and broom snakeweed are invading this desert grassland habitat.

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[6] Johnson, R. Roy. The biota of Sierra Ancha, Gila County, Arizona. 114 pp., 1960. (Unpublished master's thesis on file at Department of Zoology, University of Arizona, Tucson.)

[7] Little, Elbert L. Jr. Amphibians and reptiles of the Roosevelt Reservoir Area, Arizona. Copeia 4: 260-265. 1940.

[8] American Ornithologists' Union. Check-list of North American birds. Ed. 5, 691 pp. Baltimore: The Lord Baltimore Press, Inc. 1957.

[9] Blair, W. F., Blair, A. P., Brodkorb, P., and others. Vertebrates of the United States. 819 pp., illus. New York: McGraw-Hill Book Co., Inc. 1957.

Rare -- Familiarity with habitat requirements of the species and persistent effort are necessary to locate the species

Residence status of birds is indicated as follows:

Resident -- Found in the habitat yearlong
Summer resident -- Breeds in the habitat during the summer months
Visitor -- Found in the habitat during specific seasons of the year
Transient -- Stops over in the habitat for short periods in the course of migration

COMMON AND BOTANICAL NAMES OF PLANTS MENTIONED

Perennial Grasses

Bluegrass, Kentucky
Poa pratensis L.

Curlymesquite
Hilaria belangeri (Steud.) Nash

Grama, black
Bouteloua eriopoda Torr.

Grama, blue
Bouteloua gracilis (H.B.K.) Lag.

Grama, hairy
Bouteloua hirsuta Lag.

Grama, side-oats
Bouteloua curtipendula (Michx.) Torr.

Orchardgrass
Dactylis glomerata L.

Junegrass, Prairie
Koeleria cristata (L.) Pers.

Forbs

Bracken
Pteridium aquilinum (L.) Kuhn

Columbine, golden
Aquilegia chrysantha A. Gray

Monkeyflower, common
Mimulus guttatus DC.

Trees and Shrubs

Alder, Arizona
Alnus oblongifolia Torr.

Aspen, quaking
Populus tremuloides Michx.

Boxelder
Acer negundo L.

Buckthorn, hollyleaf
Rhamnus crocea Nutt.

Ceanothus, desert
Ceanothus greggii Gray

Cholla
Opuntia spp.

Douglas-fir
Pseudotsuga menziesii (Mirb.) Franco

Fir, white
Abies concolor (Gord. and Glend) Lindl.

Locust, New-Mexican
Robinia neomexicana A. Gray

Manzanita, pointleaf
Arctostaphylos pungens H.B.K.

Maple, bigtooth
Acer grandidentatum Nutt.

Mesquite, velvet
Prosopis velutina (Woot.) Sarg.

Mountainmahogany, birchleaf
Cercocarpus betuloides Nutt.

Oak, Arizona white
Quercus arizonica Sarg.

Oak, Emory
Quercus emoryi Torr.

Oak, Gambel
Quercus gambelii Nutt.

Oak, shrub live
Quercus turbinella Greene

Pine, ponderosa
Pinus ponderosa Lawson

Silktassel, Wright
Garrya wrightii Torr.

Snakeweed, broom
Gutierrezia sarothrae (Pursh) Britt & Rusby

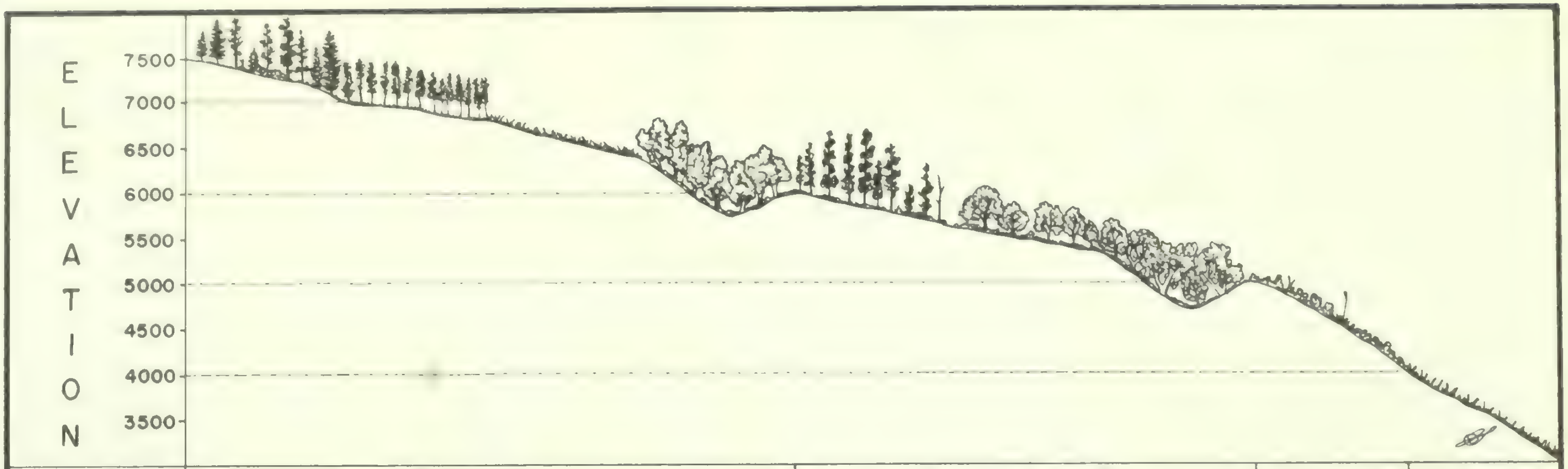
Snowberry, mountain
Symphoricarpos oreophilus A. Gray

Sumac, skunkbush
Rhus trilobata Nutt.

Sycamore, Arizona
Platanus wrightii S. Wats.

Walnut, Arizona
Juglans major (Torr.) Heller

Yucca
Yucca spp.



MACRO HABITAT	PINE-FIR				PONDEROSA PINE			CHAPARRAL	DESERT GRASSLAND
MICRO HABITAT	PINE-FIR	ASPEN	FOREST OPENING	ALDER-MAPLE	PINE	EMORY OAK	OAK-SYCAMORE		
DOMINANT VEGETATION	Douglas-fir White fir Ponderosa pine	Quaking aspen Mountain snowberry	Kentucky bluegrass Orchardgrass	Bigtooth maple Arizona alder Boxelder	Ponderosa pine New Mexican locust Gambel oak	Emory oak Mountain mahogany Manzanita	Arizona sycamore Arizona walnut Arizona white oak	Shrub live oak [illegible] [illegible]	Broom snakeweed Side-oats grama Hairy grama
AMPHIBIANS AND REPTILES	Eastern fence lizard Short-horned lizard Black-tailed rattlesnake			Canyon treefrog Leopard frog Mexican garter snake	Eastern fence lizard Short-horned lizard Black-tailed rattlesnake	Greater earless lizard Tree lizard Western garter snake	Canyon treefrog Leopard frog Mexican garter snake	Banded gecko Collared lizard Mexican black-headed snake Striped whipsnake	Gila monster Western rattlesnake Western whiptail
BIRDS	Hermit thrush Hairy woodpecker Red crossbill Brown creeper Sharp-shinned hawk Red-breasted nuthatch	Ruby-crowned kinglet Warbling vireo Red crossbill Green-tailed towhee Western wood pewee Orange-crowned warbler	Rufous hummingbird Pine siskin Slate-colored junco Robin	Zone-tailed hawk Pygmy owl Downy woodpecker Western flycatcher Red-faced warbler	Western bluebird Chipping sparrow Band-tailed pigeon Acorn woodpecker Pygmy nuthatch Lazuli bunting	Hutton's vireo Rufous-sided towhee Mexican ultramarine jay Common bushtit Blue-gray gnatcatcher	Cooper's hawk Screech owl Western kingbird Bridled titmouse Painted redstart Hooded oriole	Poor-will Scrub jay Canyon wren Plain titmouse Gray vireo Black-chinned sparrow	Mockingbird Brown towhee Loggerhead shrike Roadrunner Verdin Phainopepla
MAMMALS	Cliff chipmunk Mexican packrat Black bear Mountain lion Mule deer Elk	Valley pocket gopher Desert harvest mouse Eastern cottontail Brush mouse	Valley pocket gopher Desert harvest mouse Deer mouse Mexican vole Whitetail deer	Valley pocket gopher Black bear Raccoon	Tassel-eared squirrel Porcupine Striped skunk Whitetail deer Rock squirrel Gray fox	White-throated packrat Ringtail Bobcat Whitetail deer Western spotted skunk	Arizona gray squirrel Raccoon Western spotted skunk	Peccary California brown bat Western pipistrelle Ringtail Whitetail deer	Peccary Mexican free-tail bat Northern brown bat Ringtail Bobcat

CHECKLIST OF VERTEBRATES AND HABITAT RELATIONS

Common and scientific names	Relative abundance	Resident status	Location of museum collection	Additional notes
FISHES:				
Salmons, trouts, and chars (Salmonidae)				
Rainbow trout *Salmo gairdneri* Richardson	Rare	Resident	--	Introduced in Workman Creek; alder-maple riparian
Brook trout *Salvelinus fontinalis* (Mitchill)	Rare	Resident	--	Introduced in Workman Creek; alder-maple riparian
AMPHIBIANS:				
Tree frogs (Hylidae)				
Canyon tree frog *Hyla arenicolor* Cope	Common	Resident	USNM	Oak-sycamore and alder-maple riparian
Frogs (Ranidae)				
Leopard frog *Rana pipiens* Schreber	Rare	Resident	USNM	Oak-sycamore and alder-maple riparian
Tarahumara frog *Rana tarahumarae* Boulenger	Abundant	Resident	USNM	Oak-sycamore riparian
REPTILES:				
Gekos (Gekkonidae)				
Banded gecko *Coleonyx variegatus* (Baird)	Rare	Resident	USNM	Chaparral
Iguanas (Iguanidae)				
Collared lizard *Crotaphytus collaris* (Say)	Common	Resident	USNM	Chaparral
Greater earless lizard *Holbrookia texana* (Troschel)	Rare	Resident	USNM	Chaparral
Clark's spiny lizard *Sceloporus clarki* Baird and Girard	Common	Resident	USNM	Chaparral
Eastern fence lizard *Sceloporus undulatus* (Latreille)	Common	Resident	USNM	Pine-fir, ponderosa pine, chaparral
Tree lizard *Uta ornata* Baird and Girard	Abundant	Resident	USNM	Chaparral
Short-horned lizard *Phrynosoma douglassi* (Bell)	Common	Resident	USNM	Pine-fir, ponderosa pine, chaparral
Lateral fold lizards (Anguidae)				
Arizona alligator lizard *Gerrhonotus kingi* (Gray)	Rare	Resident	USNM	Pine-fir, ponderosa pine, chaparral
Beaded lizards (Helodermatidae)				
Gila monster *Heloderma suspectum* Cope	Rare	Resident	USNM	Chaparral
Teids (Teidae)				
Western whiptail *Cnemidophorus tigris* Baird and Girard	Rare	Resident	USNM	Chaparral
Spotted whiptail *Cnemidophorus sacki* Wiegmann	Common	Resident	USNM	Chaparral
Skinks (Scincidae)				
Great Plains skink *Eumeces obsoletus* (Baird and Girard)	Rare	Resident	USNM	Chaparral
Blind snakes (Leptotyphlopidae)				
Western blind snake *Leptotyphlops humilis* (Baird and Girard)	Rare	Resident	USNM	Chaparral
Colubrids (Colubridae)				
Mexican garter snake *Thamnophis eques* (Reuss)	Common	Resident	USNM	Oak-sycamore and alder-maple riparian near permanent water
Western garter snake *Thamnophis elegans* (Baird and Girard)	Common	Resident	USNM	Oak-sycamore and alder-maple riparian near water
Sonora whipsnake *Masticophis bilineatus* Jan.	Rare	Resident	USNM	Chaparral

CHECKLIST OF VERTEBRATES AND HABITAT RELATIONS
(continued)

Common and scientific names	Relative abundance	Resident status	Location of museum collection	Additional notes
Striped whipsnake *Masticophis taeniatus* (Hallowell)	Common	Resident	USNM	Chaparral
Mountain patch-nosed snake *Salvadora grahamiae* Baird and Girard	Common	Resident	USNM	Chaparral
Gopher snake *Pituophis catenifer* (Blainville)	Common	Resident	USNM	Chaparral
Sonora mountain kingsnake *Lampropeltis pyromelana* (Cope)	Common	Resident	USNM	Pine-fir, ponderosa pine, chaparral
Night snake *Hypsiglena torquata* Gunther	Rare	Resident	USNM	Chaparral
Mexican black-headed snake *Tantilla atriceps* (Gunther)	Rare	Resident	USNM	Chaparral
Pit vipers (Crotalidae)				
Black-tailed rattlesnake *Crotalus molossus* Baird and Girard	Common	Resident	USNM	Pine-fir, ponderosa pine, chaparral
Western rattlesnake *Crotalus viridis* (Rafinesque)	Common	Resident	USNM	Chaparral
BIRDS:				
American vultures (Cathartidae)				
Turkey vulture *Cathartes aura* (Linnaeus)	Common	Summer resident	Sight	Pine-fir, ponderosa pine, chaparral, desert grassland; nests in rocky cliffs
Hawks, old-world vultures, and harriers (Accipitridae)				
Goshawk *Accipiter gentilis* (Linnaeus)	Rare	Transient	Sight	Pine-fir, ponderosa pine
Sharp-shinned hawk *Accipiter striatus* Vieillot	Rare	Summer resident	Sight	Nests in pine-fir, mainly deep forest
Cooper's hawk *Accipiter cooperii* (Bonaparte)	Rare	Summer resident	Sight	Nests in oak-sycamore-walnut riparian
Red-tailed hawk *Buteo jamaicensis* (Gmelin)	Common	Resident	Sight	Breeds in pine-fir, ponderosa pine, chaparral, and desert grassland, in open situations
Swainson's hawk *Buteo swainsoni* Bonaparte	Rare	Transient	Sight	Pine-fir, ponderosa pine
Zone-tailed hawk *Buteo albonotatus* Kaup	Rare	Summer resident	Sight	Breeds in pine-fir and ponderosa pine in alder-maple riparian
Golden eagle *Aquila chrysaetos* (Linnaeus)	Rare	Transient	Sight	--
Bald eagle *Haliaeetus leucocephalus* (Linnaeus)	Rare	Transient	Sight	-
Caracaras and falcons (Falconidae)				
Peregrine falcon *Falco peregrinus* Tunstall	Rare	Transient	Sight	--
Sparrow hawk *Falco sparverius* Linnaeus	Rare	Transient	Sight	--
Quails, pheasants, and peacocks (Phasianidae)				
Gambel's quail *Lophortyx gambelii* Gambel	Common	Resident	Sight	Chaparral and desert grassland
Harlequin quail *Cyrtonyx montezumae* (Vigors)	Rare	Resident	Sight	Chaparral; (not recorded in recent years)
Turkeys (Meleagridioae)				
Turkey *Meleagris gallopavo* Linnaeus	Common	Resident	Sight	Nests in pine-fir and ponderosa pine; winters in chaparral
Pigeons and doves (Columbidae)				
Band-tailed pigeon *Columba fasciata* Say	Common	Summer resident	Sight	Pine-fir and ponderosa pine; nests low in pine trees
White-winged dove *Zenaida asiatica* Linnaeus	Rare	Summer resident	Sight	Desert grassland
Mourning dove *Zenaidura macroura* (Linnaeus)	Rare	Summer resident	Sight	Breeds in pine-fir, ponderosa pine, chaparral, and desert grassland

CHECKLIST OF VERTEBRATES AND HABITAT RELATIONS
(continued)

Common and scientific names	Relative abundance	Resident status	Location of museum collection	Additional notes
Cuckoos, roadrunners, and anis (Cuculidae)				
Roadrunner *Geococcyx californianus* (Lesson)	Rare	Resident	Sight	Chaparral and desert grassland; nests low in shrubs and cacti
Typical owls (Strigidae)				
Screech owl *Otus asio* (Linnaeus)	Common	Summer resident	JSW	Breeds in oak-sycamore riparian; nests low to midway in tall trees
Flammulated owl *Otus flammeolus* (Kaup)	Common	Summer resident	JSW	Breeds in pine-fir and ponderosa pine; prefers concealment in large trees
Great horned owl *Bubo virginianus* (Gmelin)	Rare	Resident	Sight	Pine-fir, ponderosa pine, chaparral, and desert grassland
Pygmy owl *Glaucidium gnoma* Wagler	Rare	Resident	Sight	Pine-fir and ponderosa pine in alder-maple riparian; prefers diurnal and nocturnal concealment in thick foliage
Elf owl *Micrathene whitneyi* (Cooper)	Rare	Resident	JSW	Chaparral in oak-sycamore riparian; prefers to perch low to midway in small to medium-sized trees
Spotted owl *Strix occidentalis* (Xantus)	Rare	Resident	Sight	Pine-fir and ponderosa pine; prefers edges of natural openings
Goatsuckers (Caprimulgidae)				
Whip-poor-will *Caprimulgus vociferus* Wilson	Common	Summer resident	Sight	Pine-fir and ponderosa pine; prefers natural openings and adjacent forest edges
Poor-will *Phalaenoptilus nuttallii* (Audubon)	Common	Summer resident	JSW	Openings in chaparral; rests on ground
Common nighthawk *Chordeiles minor* (Forster)	Rare	Transient	Sight	Pine-fir and ponderosa pine
Lesser nighthawk *Chordeiles acutipennis* (Hermann)	Rare	Resident	Sight	Desert grassland; rests on ground and forages in the air
Swifts (Apodidae)				
White-throated swift *Aeronautes saxatalis* (Woodhouse)	Common	Summer resident	Sight	Breeds in rocky cliffs in chaparral and desert grassland; forages in the air
Hummingbirds (Trochilidae)				
Black-chinned hummingbird *Archilochus alexandri* (Bourcier and Mulsant)	Common	Summer resident	JSW	Chaparral in oak-sycamore riparian; prefers to perch in low trees and shrubs; forages over flowers
Broad-tailed hummingbird *Selasphorus platycercus* (Swainson)	Common	Summer resident	JSW	Pine-fir and ponderosa pine where red or pinkish flowers grow
Rufous hummingbird *Selasphorus rufus* (Gmelin)	Common	Fall transient	JSW	Pine-fir and ponderosa pine; prefers to forage in clearings and natural openings
Calliope hummingbird *Stellula calliope* (Gould)	Rare	Fall transient	JSW	Pine-fir around natural openings
Rivoli's hummingbird *Eugenes fulgens* (Swainson)	Rare	Transient	Sight	Pine-fir
Woodpeckers and wrynecks (Picidae)				
Red-shafted flicker *Colaptes cafer* (Gmelin)	Common	Resident	Sight	Summers in pine-fir and ponderosa pine; winters in chaparral and desert grassland; forages in any large trees
Acorn woodpecker *Melanerpes formicivorus* (Swainson)	Common	Resident	Sight	Pine-fir and ponderosa pine; feeds high in conifers
Lewis' woodpecker *Asyndesmus lewis* (Gray)	Rare	Spring and fall transient	Sight	Pine-fir
Yellow-bellied sapsucker *Sphyrapicus varius* (Linnaeus)	Common	Spring and fall transient	Sight	Pine-fir and ponderosa pine; feeds low to midway in deciduous trees
Hairy woodpecker *Dendrocopos villosus* (Linnaeus)	Rare	Resident	JSW	Pine-fir; feeds midway to high in most trees
Downy woodpecker *Dendrocopos pubescens* (Linnaeus)	Common	Resident	JSW	Breeds in pine-fir in alder-maple riparian; feeds low to midway in most trees
Ladder-backed woodpecker *Dendrocopos scalaris* Wagler	Rare	Resident	Sight	Desert grassland in oak-sycamore riparian; feeds low in shrubs, agaves, and trees

CHECKLIST OF VERTEBRATES AND HABITAT RELATIONS
(continued)

Common and scientific names	Relative abundance	Resident status	Location of museum collection	Additional notes
Tyrant flycatchers (Tyrannidae)				
Western kingbird *Tyrannus verticalis* Say	Rare	Summer resident	JSW	Breeds in chaparral in oak-sycamore riparian; prefers to perch high in trees
Cassin's kingbird *Tyrannus vociferans* Swainson	Rare	Summer resident	JSW	Breeds in chaparral in oak-sycamore riparian; perches midway to high in trees
Ash-throated flycatcher [illegible]	Common	Summer resident	JSW	Breeds in chaparral and desert grassland in oak-sycamore riparian; feeds from low to midway in trees
Black phoebe *Sayornis nigricans* (Swainson)	Rare	Resident	Sight	Ponderosa pine in oak-sycamore riparian, and desert grassland; feeds from low brush over streams
Say's phoebe *Sayornis saya* (Bonaparte)	Rare	Summer resident	Sight	Open sites in ponderosa pine, chaparral, and desert grassland near habitations; feeds from perch low to midway in brush and trees
Dusky flycatcher *Empidonax oberholseri* Phillips	Rare	Fall transient	JSW	Pine-fir and ponderosa pine; feeds about midway in low trees
Western flycatcher *Empidonax difficilis* Baird	Rare	Summer resident	Sight	Breeds in pine-fir and ponderosa pine in alder-maple riparian; feeds from midway to high in trees
Coues' flycatcher *Contopus pertinax* Cabanis and Heine	Rare	Summer resident	Sight	Breeds in pine-fir and ponderosa pine; feeds high in conifers
Western wood pewee *Contopus sordidulus* Sclater	Common	Summer resident	JSW	Pine-fir and ponderosa pine in oak-sycamore and alder-maple riparian, and in edges of forest clearings; feeds low to midway in trees
Olive-sided flycatcher *Nuttallornis borealis* (Swainson)	Rare	Summer resident	JSW	Pine-fir and ponderosa pine; feeds midway to high in conifers
Swallows (Hirundinidae)				
Violet-green swallow *Tachycineta thalassina* (Swainson)	Common	Summer resident	Sight	Pine-fir and ponderosa pine; forages in clearings, nests in sycamores
Cliff swallow *Petrochelidon pyrrhonota* (Vieillot)	Rare	Transient	Sight	Pine-fir and ponderosa pine
Purple martin *Progne subis* (Linnaeus)	Rare	Transient	Sight	Pine-fir and ponderosa pine
Jays, magpies, and crows (Corvidae)				
Steller's jay *Cyanocitta stelleri* (Gmelin)	Abundant	Resident	Sight	Pine-fir and ponderosa pine in summer; winters in chaparral
Scrub jay *Aphelocoma coerulescens* (Bosc)	Common	Resident	JSW	Chaparral; feeds in low trees and bushes
Mexican (Ultramarine) jay *Aphelocoma ultramarina* (Bonaparte)	Common	Resident	JSW	Ponderosa pine in oak-sycamore and alder-maple riparian; feeds on ground and low in trees
Common raven *Corvus corax* Linnaeus	Common	Resident	Sight	Pine-fir, ponderosa pine, chaparral, and desert grassland
Common crow *Corvus brachyrhynchos* Brehm	Rare	Transient	Sight	Pine-fir and ponderosa pine
Titmice, verdins, and bushtits (Paridae)				
Mountain chickadee [illegible]	Abundant	Resident	JSW	Pine-fir and ponderosa pine; feeds throughout bushes and trees
Plain titmouse *Parus inornatus* Gambel	Rare	Resident	JSW	Chaparral; feeds throughout low trees and shrubs
Bridled titmouse *Parus wollweberi* (Bonaparte)	Common	Resident	Sight	Sycamore-walnut riparian; feeds low to midway in trees
Verdin *Auriparus flaviceps* (Sundevall)	Rare	Resident	Sight	Desert grassland; feeds in low trees and shrubs
Common bushtit *Psaltriparus minimus* (Townsend)	Common	Resident	Sight	Chaparral; feeds in low trees and shrubs

CHECKLIST OF VERTEBRATES AND HABITAT RELATIONS
(continued)

Common and scientific names	Relative abundance	Resident status	Location of museum collection	Additional notes
Nuthatches (Sittidae)				
White-breasted nuthatch *Sitta carolinensis* Latham	Common	Resident	JSW	Pine-fir and ponderosa pine in oak-sycamore and alder-maple riparian; feeds low to midway in trees
Red-breasted nuthatch *Sitta canadensis* Linnaeus	Rare	Summer resident	JSW	Pine-fir; feeds in tops of tall conifers
Pygmy nuthatch *Sitta pygmaea* Vigors	Abundant	Summer resident	Sight	Pine-fir and ponderosa pine; feeds throughout conifers
Creepers (Certhiidae)				
Brown creeper *Certhia familiaris* Linnaeus	Common	Summer resident	Sight	Pine-fir; feeds throughout conifers
Wrens (Troglodytidae)				
House wren *Troglodytes aedon* Vieillot	Common	Summer resident	Sight	Pine-fir around openings and clearings; feeds in underbrush and brush piles
Bewick's wren *Thryomanes bewickii* (Audubon)	Common	Summer resident	Sight	Chaparral in oak-sycamore riparian; feeds in underbrush and brush piles
Canyon wren *Catherpes mexicanus* (Swainson)	Common	Resident	Sight	Ponderosa pine, chaparral, and desert grassland around canyon walls and cliffs
Rock wren *Salpinctes obsoletus* (Say)	Common	Summer resident	Sight	Chaparral and desert grassland around rocky hillsides
Mockingbirds and thrashers (Mimidae)				
Mockingbird *Mimus polyglottos* (Linnaeus)	Rare	Summer resident	Sight	Chaparral and desert grassland
Thrushes, solitaires, and bluebirds (Turdidae)				
Robin *Turdus migratorius* Linnaeus	Common	Resident	Sight	Pine-fir and ponderosa pine in oak-sycamore and alder-maple riparian, and forest openings
Hermit thrush *Hylocichla guttata* (Pallas)	Common	Summer resident	JSW	Pine-fir; forages on ground and low in trees and shrubs
Western bluebird *Sialia mexicana* Swainson	Common	Summer resident	Sight	Pine-fir and ponderosa pine forests; feeds on insects from high in trees near openings
Townsend's solitaire *Myadestes townsendi* (Audubon)	Common	Spring and fall transient	JSW	Ponderosa pine and chaparral
Old-world warblers, gnatcatchers, and kinglets (Sylviidae)				
Blue-gray gnatcatcher *Polioptila caerulea* (Linnaeus)	Common	Summer resident	Sight	Chaparral; feeds from low to midway in low trees
Ruby-crowned kinglet *Regulus calendula* (Linnaeus)	Common	Winter visitor	JSW	Pine-fir, ponderosa pine, and chaparral; feeds throughout trees and shrubs
Wagtails and pipits (Motacillidae)				
Water pipit *Anthus spinoletta* (Linnaeus)	Rare	Spring and fall transient	JSW	Pine-fir; feeds around forest openings
Waxwings (Bombycillidae)				
Cedar waxwing *Bombycilla cedrorum* Vieillot	Rare	Fall transient	Sight	Chaparral
Silky flycatchers (Ptilogonatidae)				
Phainopepla *Phainopepla nitens* (Swainson)	Rare	Resident	Sight	Desert grassland; feeds in the top of low trees and shrubs
Shrikes (Laniidae)				
Loggerhead shrike *Lanius ludovicianus* Linnaeus	Rare	Summer resident	Sight	Chaparral and desert grassland
Vireos (Vireonidae)				
Hutton's vireo *Vireo huttoni* Cassin	Common	Summer resident	JSW	Ponderosa pine in oak-sycamore-walnut and alder-maple riparian; feeds throughout deciduous trees
Gray vireo *Vireo vicinior* Coues	Common	Summer resident	JSW	Chaparral, commonly in pinyon trees; feeds throughout low trees

CHECKLIST OF VERTEBRATES AND HABITAT RELATIONS
(continued)

Common and scientific names	Relative abundance	Resident status	Location of museum collection	Additional notes
Solitary vireo [illegible]	Common	Summer resident	JSW	Breeds in pine-fir and ponderosa pine; feeds from midway to tops of trees
Warbling vireo *Vireo gilvus* (Vieillot)	Common	Summer resident	Sight	Pine-fir and ponderosa pine
Wood warblers (Parulidae)				
Orange-crowned warbler *Vermivora celata* (Say)	Common	Spring and fall transient	Sight	Pine-fir; feeds from low to high in shrubs and trees
Virginia's warbler *Vermivora virginiae* (Baird)	Common	Summer resident	JSW	Nests in pine-fir and ponderosa pine
Lucy's warbler *Vermivora luciae* (Cooper)	Rare	Summer resident	JSW	Ponderosa pine in oak-sycamore riparian
Olive warbler *Peucedramus taeniatus* (Du Bus)	Rare	Summer resident	Sight	Breeds in pine-fir
Audubon's warbler *Dendroica auduboni* (Townsend)	Common	Spring and fall transient	Sight	Pine-fir, ponderosa pine, chaparral, and desert grassland
Black-throated gray warbler *Dendroica nigrescens* (Townsend)	Common	Summer resident	JSW	Ponderosa pine in oak-sycamore riparian; feeds from low to midway in shrubs and trees
Townsend's warbler *Dendroica townsendi* (Townsend)	Common	Spring and fall transient	JSW	Pine-fir
Hermit warbler *Dendroica occidentalis* (Townsend)	Common	Fall transient	JSW	Pine-fir
Grace's warbler *Dendroica graciae* [illegible]	Common	Summer resident	JSW	Ponderosa pine, usually found near middle or top of the conifers
MacGillivray's warbler *Oporornis tolmiei* (Townsend)	Common	Fall transient	JSW	Pine-fir; feeds in shrubs around forest openings
Red-faced warbler *Cardellina rubrifrons* [illegible]	Common	Summer resident	JSW	Pine-fir in alder-maple riparian; feeds throughout conifers
Wilson's warbler *Wilsonia pusilla* (Wilson)	Common	Spring and fall transient	Sight	Pine-fir and ponderosa pine in alder-maple and oak-sycamore-maple riparian, and near edges of forest openings
Painted redstart *Setophaga picta* Swainson	Common	Summer resident	JSW	Pine-fir and ponderosa pine in oak-sycamore and alder-maple riparian; feeds in low trees and underbrush
Meadowlarks, blackbirds, and orioles (Icteridae)				
Hooded oriole *Icterus cucullatus* Swainson	Rare	Summer resident	Sight	Ponderosa pine and chaparral in oak-sycamore riparian
Scott's oriole *Icterus parisorum* Bonaparte	Common	Summer resident	JSW	Chaparral and desert grassland wherever yuccas occur
Brewer's blackbird *Euphagus cyanocephalus* (Wagler)	Rare	Spring and fall transient	Sight	Pine-fir in natural openings
Brown-headed cowbird *Molothrus ater* Boddaert	Rare	Summer resident	Sight	Pine-fir, ponderosa pine, and chaparral in oak-sycamore riparian
Tanagers (Thraupidae)				
Western tanager [illegible]	Common	Summer resident	JSW	Pine-fir; feeds midway to high in trees
Hepatic tanager *Piranga flava* (Vieillot)	Common	Summer resident	JSW	Pine-fir and ponderosa pine; feeds in lower levels of medium-sized pines and Gambel oaks
Grosbeaks, finches, sparrows, and buntings (Fringillidae)				
Cardinal *Richmondena cardinalis* (Linnaeus)	Rare	[illegible] resident	Sight	Chaparral and desert grassland
Black-headed grosbeak *Pheucticus melanocephalus* (Swainson)	Common	Summer resident	Sight	Pine-fir, ponderosa pine, and Gambel oak

CHECKLIST OF VERTEBRATES AND HABITAT RELATIONS
(continued)

Common and scientific names	Relative abundance	Resident status	Location of museum collection	Additional notes
Blue grosbeak *Guiraca caerulea* (Linnaeus)	Rare	Summer resident	Sight	Ponderosa pine in oak-sycamore riparian
Indigo bunting *Passerina cyanea* (Linnaeus)	Rare	Summer resident	JSW	Pine-fir and ponderosa pine forests in shrubs around forest openings
Lazuli bunting *Passerina amoena* (Say)	Common	Summer resident	Sight	Pine-fir and ponderosa pine in shrubs in and around forest openings
Evening grosbeak *Hesperiphona vespertina* (Cooper)	Rare	Summer resident	JSW	Pine-fir forest near forest openings
Cassin's finch *Carpodacus cassinii* Baird	Rare	Transient	JSW	Pine-fir and ponderosa pine; usually observed midway to high in trees
House finch *Carpodacus mexicanus* (Muller)	Common	Resident	Sight	Chaparral and desert grassland
Pine siskin *Spinus pinus* (Wilson)	Common	Winter visitor	Sight	Pine-fir forests in and around forest openings
Lesser goldfinch *Spinus psaltria* (Say)	Common	Summer resident	JSW	Pine-fir and ponderosa pine in oak-sycamore and alder-maple riparian
Red crossbill *Loxia curvirostra* Linnaeus	Rare	Summer resident	JSW	Pine-fir near forest openings; feeds throughout conifers
Green-tailed towhee *Chlorura chlorura* (Audubon)	Common	Summer resident	JSW	Pine-fir, ponderosa pine, and chaparral
Rufous-sided towhee *Pipilo erythrophthalmus* (Linnaeus)	Common	Summer resident	Sight	Pine-fir, ponderosa pine, and chaparral where there is dense undergrowth
Brown towhee *Pipilo fuscus* Swainson	Common	Resident	JSW	Chaparral and desert grassland; feeds on ground and in low shrubs
Black-throated sparrow *Amphispiza bilineata* (Cassin)	Common	Summer resident	JSW	Desert grassland where cholla are present
Slate-colored junco *Junco hyemalis* (Linnaeus)	Common	Winter visitor	JSW	Pine-fir, ponderosa pine, and chaparral
Chipping sparrow *Spizella passerina* (Bechstein)	Common	Summer resident	JSW	Pine-fir and ponderosa pine, usually found around forest openings
Black-chinned sparrow *Spizella atrogularis* (Cabanis)	Common	Summer resident	JSW	Chaparral in dense cover
White-crowned sparrow *Zonotrichia leucophrys* (Forster)	Common	Spring and fall transient	Sight	Pine-fir, ponderosa pine, chaparral, and desert grassland
MAMMALS:				
Bats (Chiroptera)				
Northern brown bat *Myotis keeni* (Merriam)	Rare	Resident	UA	Pine-fir, ponderosa pine, chaparral, and desert grassland around rocky cliffs
California brown bat *Myotis californicus* (Audubon and Bachman)	Common	Resident	UA	Chaparral and desert grassland around rocky cliffs
Masked brown bat *Myotis subulatus* (Say)	Common	Resident	UA	Chaparral and desert grassland around rocky cliffs
Western pipistrelle *Pipistrellus hesperus* (Allen)	Common	Resident	UA	Chaparral and desert grassland around rocky cliffs
Big brown bat *Eptesicus fuscus* (Beauvois)	Rare	Resident	UA	Chaparral and desert grassland around rocky cliffs
Pallid bat *Antrozous pallidus* (Le Conte)	Rare	Resident	UA	Pine-fir, ponderosa pine, and desert grassland around rocky cliffs
Mexican freetail bat *Tadarida mexicana* (Saussure)	Common	Summer resident	JSW	Chaparral around rocky cliffs
Rabbits (Lagomorpha)				
Eastern cottontail *Sylvilagus floridanus* (Allen)	Common	Resident	UA	Pine-fir, ponderosa pine, and chaparral

CHECKLIST OF VERTEBRATES AND HABITAT RELATIONS

(continued)

Common and scientific names	Relative abundance	Resident status	Location of museum collection	Additional notes
Rodents (Rodentia)				
Tassel-eared squirrel *Sciurus aberti* Woodhouse	Common	Resident	UA	Pine-fir and ponderosa pine
Arizona gray squirrel *Sciurus arizonensis* Coues	Rare	Resident	MVZ UA	Ponderosa pine and chaparral in oak-sycamore riparian
Rock squirrel *Citellus variegatus* (Erxleben)	Common	Resident	USNM MVZ	Pine-fir, ponderosa pine, chaparral, and desert grassland in rocky terrain
Cliff chipmunk *Eutamias dorsalis* (Baird)	Common	Resident	USNM MVZ	Pine-fir, ponderosa pine, chaparral, and desert grassland around cliffs and logs
Valley pocket gopher *Thomomys bottae* (Eydoux and Gervais)	Common	Resident	UA	Pine-fir and ponderosa pine in forest openings
Desert harvest mouse *Reithrodontomys megalotis* (Baird)	Common	Resident	MVZ UA	Pine-fir and ponderosa pine in natural openings
Deer mouse *Peromyscus maniculatus* (Wagner)	Common	Resident	UA	Pine-fir and ponderosa pine in forest openings
Brush mouse *Peromyscus boylei* (Baird)	Abundant	Resident	USNM MVZ UA	Pine-fir, ponderosa pine, and chaparral
White-throated packrat *Neotoma albigula* Hartley	Common	Resident	USNM MVZ	Favorite habitat in chaparral
Mexican packrat *Neotoma mexicana* Baird	Common	Resident	MVZ UA	Pine-fir and ponderosa pine
Mexican vole *Microtus mexicanus* (Saussure)	Rare	Resident	MVZ	Pine-fir and ponderosa pine in natural openings of dense grass
Porcupine *Erethizon dorsatum* (Linnaeus)	Rare	Resident	Sight	Pine-fir and ponderosa pine
Flesh-eaters (Carnivora)				
Coyote *Canis latrans* Say	Rare	Resident	Sight	Pine-fir, ponderosa pine, chaparral, and desert grassland
Gray fox *Urocyon cinereoargenteus* (Schreber)	Rare	Resident	Sight	Pine-fir, ponderosa pine, chaparral, and desert grassland
Black bear *Ursus americanus* Pallas	Common	Resident	Sight	Pine-fir, ponderosa pine, and chaparral
Ringtail *Bassariscus astutus* (Lichtenstein)	Rare	Resident	Sight	Chaparral and desert grassland
Raccoon *Procyon lotor* (Linnaeus)	Rare	Resident	Sight	Pine-fir and ponderosa pine in alder-maple and oak-sycamore riparian
Common striped skunk *Mephitis mephitis* (Schreber)	Common	Resident	Sight	Ponderosa pine and chaparral
Western rooter skunk *Conepatus mesoleucus* (Lichtenstein)	Rare	Resident	Sight	Chaparral
Mountain lion *Felis concolor* Linnaeus	Rare	Resident	Sight	Pine-fir and ponderosa pine
Bobcat *Lynx rufus* (Schreber)	Rare	Resident	Sight	Pine-fir, ponderosa pine, chaparral, and desert grassland
Even-toed ungulates (Artiodactyla)				
Collared peccary *Tayassu tajacu* (Linnaeus)	Common	Resident	Sight	Chaparral and desert grassland
Elk *Cervus canadensis* Erxleben	Rare	Resident	Sight	Pine-fir and ponderosa pine
Whitetail deer *Odocoileus virginianus* (Zimmermann)	Common	Resident	Sight	Pine-fir, ponderosa pine, and chaparral
Mule deer *Odocoileus hemionus* (Rafinesque)	Rare	Resident	Sight	Pine-fir and ponderosa pine

Reynolds, Hudson G., and Johnson, R. Roy.
1964. Habitat relations of vertebrates of the Sierra Ancha
Experimental Forest. U. S. Forest Serv. Res.
Paper RM-4, 16 pp., illus. Rocky Mountain Forest
and Range Experiment Station, Fort Collins, Colorado.

Describes the Experimental Forest in general terms, characterizes the more important vertebrate habitats, and presents a checklist of vertebrates together with notes as to their relative abundance, seasonal occurrence, and macro- and microhabitats. Includes 125 birds, 33 mammals, 24 reptiles, 3 amphibians, and 2 fish.

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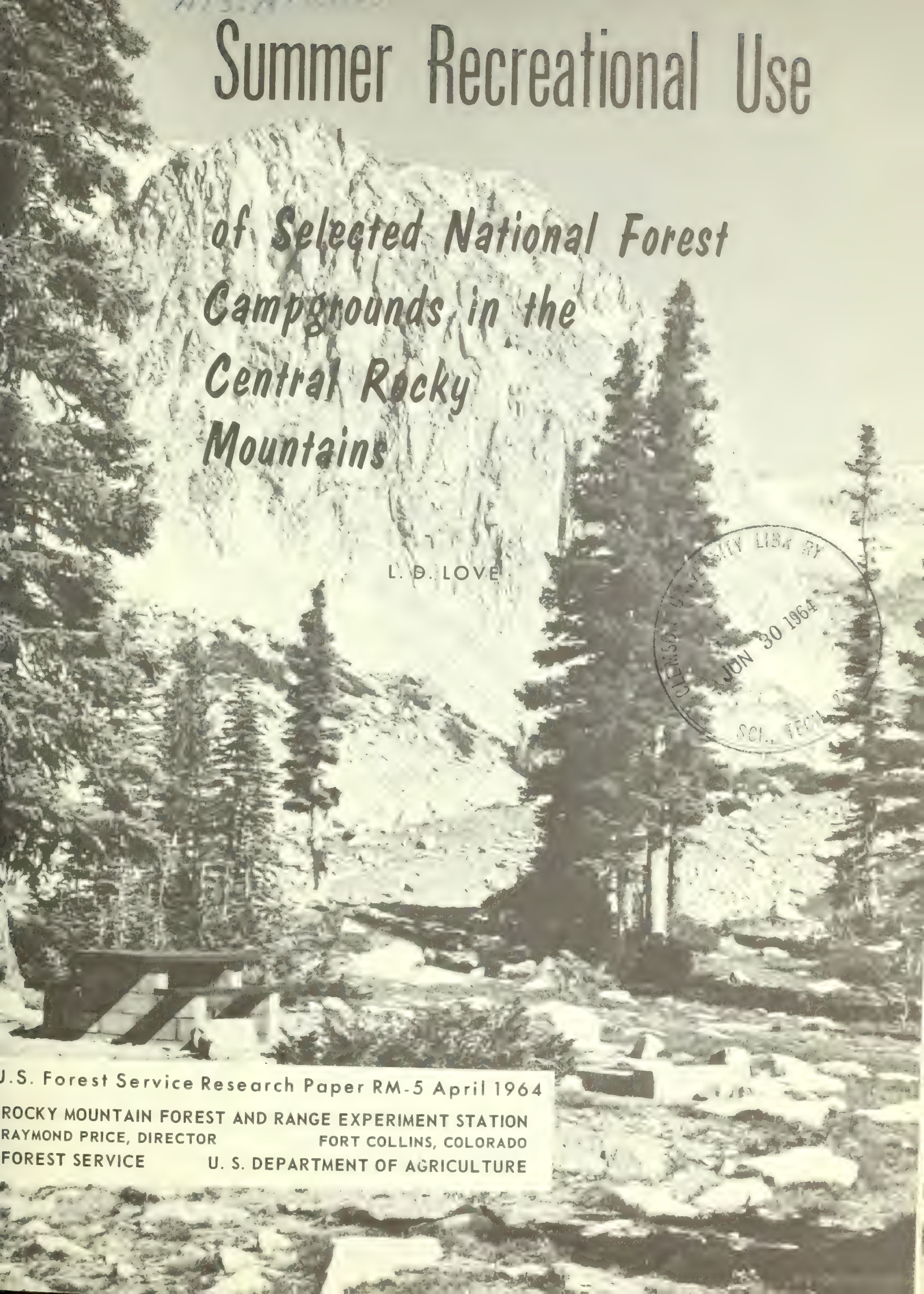
Summer Recreational Use

# of Selected National Forest Campgrounds in the Central Rocky Mountains

L. D. LOVE



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U.S. Forest Service Research Paper RM-5 April 1964

ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION
RAYMOND PRICE, DIRECTOR FORT COLLINS, COLORADO
FOREST SERVICE U. S. DEPARTMENT OF AGRICULTURE

ABOUT THE COVER:

Timberline vegetation and rugged mountain peaks attract visitors to the Mirror Lake campground in the Snowy Range, Medicine Bow National Forest, Wyoming.

U. S. Forest Service Research Paper RM-5 April 1964

SUMMER RECREATIONAL USE OF SELECTED NATIONAL FOREST CAMPGROUNDS IN THE CENTRAL ROCKY MOUNTAINS

by

L. D. Love, Research Forester

Rocky Mountain Forest and Range Experiment Station[1]

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[1] Central headquarters maintained in cooperation with Colorado State University at Fort Collins.

Summer Recreational Use of Selected National Forest Campgrounds in the Central Rocky Mountains

by

L. D. Love

SUMMARY

From mid-June to mid-September 1962, 12 selected campgrounds were observed in the National Forests of Arizona, New Mexico, Colorado, Wyoming, and South Dakota. The purpose of the study was to establish patterns of recreational use in order to guide future development and management.

Highlights are:

1. In-State parties visiting the 12 campgrounds were more numerous than out-State. Camping parties slightly outnumbered day-use parties.

2. About 10 percent of the total vehicles were campers (pickup with camper-back or other sleep-in vehicle). The use of tents for camping exceeded travel trailers by a ratio of 1.5 to 1. The average number of visitors per party (4.8) was greater than the average number of visitors per vehicle (3.9) because frequently two or more vehicles were used by a single party. Camping visitors per party and per vehicle were less than day-use visitors per party and vehicle.

3. The young adult (21-39 years) and children (13 years or less) were the dominant visitors. Next in importance was the middle-aged adult (40-59 years) followed by the teenager (14-20 years). The older adult (60+ years) was the most infrequent visitor.

4. Most visitor-hour use was attributed to camping. In general, about 10 percent of the total visitor-hour use was the result of day-use.

5. People who camped stayed an average of 27.35 hours per visitor. Day-users stayed an average of 2.35 hours per visitor.

6. Family units were not used uniformly. Day-use of all units averaged less than 6 hours per visitor per day. Unit use varied as follows:

Daily use per camping visitor (Hours)	Units used (Number)	Units used (Percent)
0-6	308	60
7-12	123	24
13-18	33	6
19-24	50	10
Total	514	100

7. In general, the average daily use per visitor at each family unit for both camping

and day-use was 6 hours the first period (mid-June to end of July) and 7 hours the second (August to mid-September). When contrasted to the possible total daily use, units were actually in use about 27 percent of the time.

8. Total hours of daily use per visitor at each family unit appeared to be associated with the distance certain facilities are from the units as follows:
   a. Units between 50 and 200 feet from toilets were used more than those within 50 feet or over 200 feet.
   b. Units within 150 feet of drinking water were used more than those over 150 feet.
   c. Units over 100 feet apart were used more than those closer together.
   d. Units between 50 and 200 feet from a fishing point were used more than those within 50 feet or over 200 feet.
   e. Units with a clearing of over 10 feet in radius from the fire grate were used more than those with less.

9. In the first period, 17 percent of the total family units (514) were never used; 29 percent were never used in the second period. Thus, the number of parties visiting the campgrounds could have been accommodated by about 20 percent fewer family units. A limited number of family units were selected by several new parties (a measure of popularity); for example in the first period, 10 percent of the total family units (514) were selected 5 or more times; this percentage was about the same (11 percent) during the second period.

INTRODUCTION

Quantitative information concerning recreational use of National Forest campgrounds is desirable not only to relate recreation to other forest uses, but also for the development, maintenance, and rehabilitation of forest campgrounds. The number and characteristics of recreationists, purpose and duration of visits, camping equipment used, and the occupance of family units (table, fire grate, trash container in a localized spot within a forest campground) are important considerations.

Accordingly, the use of 12 selected campgrounds in the National Forests of Arizona, New Mexico, Colorado, Wyoming, and South Dakota was systematically observed during two 4-day periods between mid-June and mid-September, 1962. The purpose of the study was to establish patterns of recreational use in order to guide development and management of such use and to identify key observations for subsequent studies.

The results of this study provide considerable information about visitors to the 12 campgrounds. Although these results cannot now be applied directly to other campgrounds, particularly those where fees are charged, the fact that some of the observations are nearly identical on all campgrounds may indicate widespread uniformity in visitor use-patterns. If future studies show additional uniformity, it should be possible to predict visitor-use patterns from the trends found in origin of visitors, age classes, length of stay, and factors associated with the selection and use of family units.

PREVIOUS WORK

Investigations by others dealing with outdoor recreationists have been conducted for a variety of purposes. Methods employed likewise have varied so that it is difficult to make direct comparisons with the results obtained from the present study. Certain general trends are apparent, but specific supporting evidence is lacking.

In a study of the economic value of State parks in Oregon (Ore. State Highway Dept., 1959),[2] it was found that 87 percent of the total visits to State parks were by in-State residents, that the average number of persons per party was 5.03, and that the average length of stay within 25 miles of parks was 2.2 days per party. This is equivalent, on the average, to 52.8 hours for a party of 5.03 persons, or 10.5 hours per visitor.

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[2] *Names and dates in parentheses refer to Literature Cited, p. 22.*

Burke[3] found, in his studies of the utilization of recreation areas, that people select and use tables in relation to distance from parking; the closer the parking the more frequent the selection and use. The trend was similar for distance from a beach. The basal area of trees within 30 feet of a table influenced the choice and use of tables; tables with trees of lower basal areas were chosen more often and used for longer periods of time. He also found that certain camp sites were preferred and used longer than others.

Hutchins and Trecker (1961), in their study of the visitors to Wisconsin State parks, found that the passenger load per car was 3.5 persons and that two-thirds of the visitors were in-State residents. Eighty percent of the visitors stayed for a day or less.

According to ORRRC (U.S. Outdoor Recreation Resources Review Commission, 1962a), single-family groups with or without children play a dominant role in areas where camping (74.5 percent) and sightseeing (66.6 percent) are major attractions. About 40 percent of the user groups included boys or girls or both 12 years of age or less, and about 23 percent included teenagers. Sixty-four percent of the user groups included one or more men between 20 and 44 years, and 65 percent included women in the 20 to 44 age bracket. About a third of the visitors to National Forests stayed between 1 and 3 days, while about half of them spent less than one-half day. About three-fourths of the groups that camped stayed for a day or more.

In another ORRRC report (1962b), it was noted that only minor male-female differences exist, especially where families or mixed groups can participate in outdoor recreation. Participation in outdoor recreation tends to decline as the age group reaches 45 to 54. Greater participation is noted in the age groups 18 to 24 and 24 to 34.

Ripley (1962), in his study of recreation impact on campgrounds and picnic sites, points out that table spacing is a minor factor because use is closely confined to the table. He noted that distance to the nearest parking area controls use, and that parking facilities could be used to foster more uniform use.

Among canoe country vacationers described by Taves, et al. (1960) a greater percentage (76 percent) of visitors who camp were in age groups 25 to 54 than in other groups. Also, about 40 percent of the campers were women.

Tocher and Kearns (1962) in their description of Utah tourism point out that travel trailers and campers (pickup with camper-back) comprise about 10 percent of the camping equipment used at public camps. They predict that the use of this kind of equipment will increase.

In discussing age of people who camp, Wagar[4] found that over half of the visitors asked were between 15 and 39 years. He also found that a high percentage of females participate in outdoor recreation activities.

The results of the present study are reasonably well substantiated by results obtained elsewhere. This is apparent with regard to proportion of in-State to out-State visitors, age classes, sex ratios, and influence of distance to parking areas on unit use. The results obtained elsewhere apply to a lesser extent to length of stay, influence of size of clearing on unit occupancy, and kinds of equipment used by outdoor recreationists.

CAMPGROUNDS STUDIED

Campgrounds representing different elevational and vegetational zones were chosen for study (table 1). The campgrounds provided both camping and day-use. Some provided additional activities, such as fishing, boating, and hiking so that the users had a variety of choices.

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[3] *Burke, Hubert D. Mapping of utilization on recreation areas. 1961. (First and second office reports on exploratory phase of the study, on file at Northeast. Forest Expt. Sta., U. S. Forest Serv., Upper Darby, Pa.)*

[4] *Wagar, J. Alan. An exploratory study of visitor motivation and attitudes toward forest recreation. 1962. (Office report on file at Northeast. Forest Expt. Sta., U. S. Forest Serv., Upper Darby, Pa.)*

Table 1.--Description of 12 campgrounds observed in four States from mid-June to mid-September 1962

Campground and National Forest	Elevation	Vegetation type	First observation period (mid-June to end of July)		Second observation period (August to mid-September)	
			Dates	Weather	Dates	Weather
	Feet					
ARIZONA:						
Rose Canyon (Coronado)	7,200	Ponderosa pine	July 20-23	Clear, warm	Aug. 31-Sept. 3 (Labor Day)	Clear, warm
Lakeside (Sitgreaves)	6,700	Ponderosa pine	July 6-9	Clear, warm	Aug. 17-20	Clear, warm
Ashurst (Coconino)	7,000	Mixed ponderosa pine and juniper	June 22-25	Clear, warm, windy	Aug. 3-6	Clear, warm, windy
NEW MEXICO:						
Fourth of July (Cibola)	8,000	Ponderosa pine-Gambel oak-bigtooth maple	July 27-30	Clear, warm; turned cloudy and stormy on July 30	Sept. 7-10	Clear, warm
Holy Ghost (Santa Fe)	8,000	Mixed conifers	June 29-July 2	Partly cloudy, warm; heavy thunderstorm on June 29, followed by clearing weather	Aug. 10-13	Partly cloudy, warm
La Sombra-Capulin (Carson)	7,800	Canyon-bottom	July 13-16	Clear, warm	Aug. 24-27	Clear, warm
COLORADO:						
Maroon Lake (White River)	10,000	Aspen predominates	July 13-16	Clear to partly cloudy; warm days; cool evenings; intermittent rain showers	Aug. 17-20	Clear to partly cloudy; warm days; cool evenings; intermittent rain showers that lasted longer than first period (Sat. & Sun.)
Echo Lake (Arapaho)	10,700	Engelmann spruce-subalpine fir-bristlecone pine	June 29-July 2	Partly cloudy, cool; hail and rainstorm on July 1	Aug. 10-13	Partly cloudy, cool; considerable wind
Walton Creek (Routt)	9,000	Engelmann spruce-subalpine fir	July 20-23	Clear; warm days; cold evenings	Aug. 31-Sept. 3 (Labor Day)	Clear; cold; dusty; cloudy and windy on Sept. 3
Chambers Lake (Roosevelt)	9,200	Lodgepole pine	June 22-25	Partly cloudy, warm days; cool evenings; intermittent rain showers	Aug. 3-6	Partly cloudy; warm days; cool evenings; intermittent rain showers
WYOMING:						
Mirror Lake (Medicine Bow)	10,500	Engelmann spruce-subalpine fir	July 6-9	Partly cloudy, cool, turning cloudy and cold on July 9	Aug. 24-27	Clear; windy; cool
SOUTH DAKOTA:						
Sheridan Point (Black Hills)	7,000	Ponderosa pine	July 27-30	Partly cloudy, warm; prolonged rainstorm on July 28	Sept. 7-10	Partly cloudy, cool; brief snowstorm on Sept. 8, turning warm on Sept. 10

Family units	Location	Supplemental information
Number		
85	20 miles northeast of Tucson	On the Mt. Lemmon highway; small artificial lake at west end provides limited fishing opportunities; improved gravel access roads are narrow and rough in several places; family units divided into 4 broad groups: 2 for group participation under special-use permit, day-use only (fig. 1); 7, day-use only; 12, travel-trailer use; 64, camping and day-use.
51	6 miles south of Show Low	Artificial lake nearby provides fishing opportunities; recreation guard visited campground daily, seasonlong; some recent rehabilitation through "Operation Outdoors" program; gravel access roads adequate for moving traffic, which often created palls of drifting dust throughout campground; family units divided into 3 broad groups: 5, day-use only; 19, travel-trailer use; remainder, camping and day-use.
50	25 miles southeast of Flagstaff	On east and west banks of Ashurst Lake, an improved natural impoundment; 1962 season was initial period of use for 32 units constructed along east side of lake under "Operation Outdoors" program; access road along west side of lake adequate for moving traffic, remainder of road under partial construction but passable; all family units, camping and day-use; 3 toilets serviced the area, others under construction.
26	40 miles southeast of Albuquerque	No special attraction at campground, but variety of trees affords pleasant surroundings; in 1960-61, old area rehabilitated and new units added under "Operation Outdoors" program; 1962 was second season of use of enlarged area; recreation guard visited campground daily, seasonlong; all family units, camping and day-use; improved gravel road narrow--in places parked vehicles interfere with moving traffic.
22	15 miles northwest of Pecos	In headwater area of Pecos River, along Holy Ghost Creek, a tributary to the river; only moderate maintenance since construction in CCC days; recreation-guard visits averaged every other day; all family units, camping and day-use -- 6 were Appalachian shelters (fig. 2); improved dirt access road is rutted and rocky in spots, fords creek in two substandard places; undeveloped spring at north end of campground provides very limited source of drinking water.
17	8 miles southeast of Taos	On U. S. Highway 64; a combination of two campgrounds with a connecting road; adjacent to Taos Creek; all family units, camping and day-use; was developed during CCC days, with little maintenance and no rehabilitation since; undeveloped spring provides limited supply of drinking water; three entrances from the highway, with interior dusty, dirt roads; access road was extremely dusty in August period; recreation-guard visits averaged every other day.
61	11 miles southwest of Aspen	In headwater area of Maroon Creek; campground is 300 feet north of Maroon Lake; trails lead into Maroon Bells-Snowmass Wild Area; in 1960-61, campground rehabilitated and new units added under "Operation Outdoors" program; 1962 was initial season of use of enlarged area; recreation guard visited campground daily, seasonlong; family units divided into 2 broad groups: 16, trailer use only; 11, day-use only; remainder, camping and day-use.
19	20 miles southwest of Idaho Springs	On Mount Evans road (Colorado Highway 103); last campground before road ascends Mt. Evans; on loop drive from Denver; 1/4 mile to Echo Lake which provides moderate fishing opportunities; established in CCC days, has had moderate maintenance; group shelter (fig. 3) is attractive, popular improvement that accommodates several unrelated parties at one time; has one council circle; all but 2 of 19 family units designated camping and day-use; recreation guard visited campground daily, seasonlong; gravel access road too narrow for 2-way traffic; congestion resulted at limited parking areas.
14	12 miles east of Steamboat Springs	Visible from U.S. Highway 40; Walton Creek, adjacent to site, provides some fishing opportunities; in 1960-61, old area rehabilitated and new units added under "Operation Outdoors" program; 1962 was second season of use for enlarged area; recreation guards visited periodically during season; all units, camping and day-use; dirt access road adequate for moving traffic; little congestion occurred.
55	60 miles west of Fort Collins	In headwater area of Cache la Poudre River, along southwest shore of Chambers Lake; recreationists travel to Chambers Lake--an artificial impoundment for water supply--for fishing and boating opportunities; in 1960-61, old area rehabilitated, new units added under "Operation Outdoors" program; 1962 was initial use period of enlarged area; recreation guard stationed at campground, seasonlong; improved gravel access road adequate for moving traffic, but some congestion in terminal parking lot; family units divided into 2 broad groups: 21, trailer use only; remaining units, camping and day-use, with 6 for day-use only.
19	30 miles west of Laramie	In Snowy Range, adjoining Mirror Lake--an improved natural lake--that provides considerable shore fishing; snowdrifts blocked entrance on July 6, but were opened by noon that day; campground extremely wet due to rapid snowmelt--several cars of first group of visitors became stuck in mud; scenic setting is site's major attraction (see cover photo); recreation guards visited periodically; some rehabilitation work under "Operation Outdoors" program had been completed; additional rehabilitation was begun late in 1962 season.
96	5 miles north of Hill City	Along U. S. Highway 85A, adjacent to Sheridan Lake where boating, fishing, water skiing, and swimming are main attractions (fig. 4); recreation guard stationed at area, seasonlong; movies were shown every other evening during first period; new units had been added to campground in 1961 with more under construction in 1962; study included the 96 available during 1962; family units were divided into two groups: 66 units, tent camping; 30 units, trailer use; 1962 was initial period of use for 25 units; access road to 25 new units often muddy and slick; remainder of road adequately accommodated moving traffic; little congestion occurred.

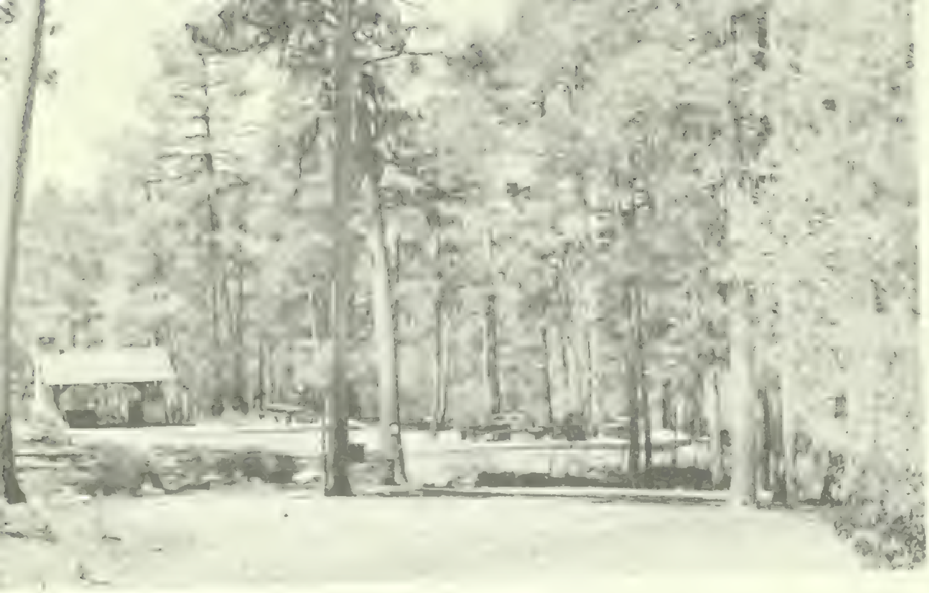
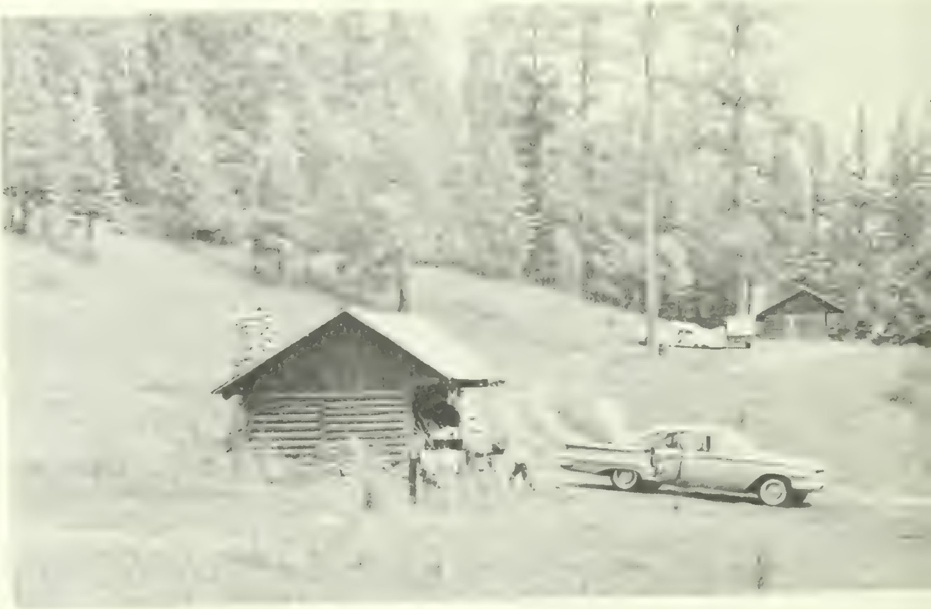


Figure 1.--
Group-participation unit at Rose Canyon campground for day-use under special-use permit. Coronado National Forest, Arizona.

Figure 2.--
Appalachian shelters are an attraction at the Holy Ghost campground. Santa Fe National Forest, New Mexico.



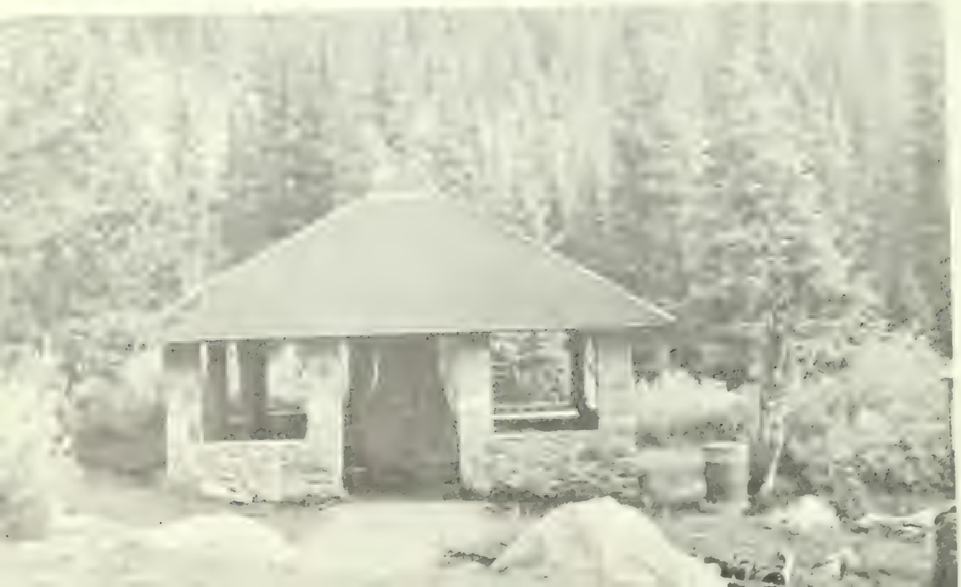


Figure 3.--
This popular group shelter lends attractiveness to the Echo Lake campground. Arapaho National Forest, Colorado.

PROCEDURES

All campgrounds were observed twice during the summer. Each observation period covered 4 days -- a Friday-through-Monday period. The number of observations at each campground depended upon the number of family units. Use of each unit was recorded hourly -- 8 a.m. to 7 p.m. (except on Mondays when the last record was made at 5 p.m.). The goal was to arrive at a census of the total use of a campground during the periods of observation.

Observations at the family units included: kind and amount of camping equipment used; size of party; age and sex classes; length of stay; and apparent activity. Data were summarized as to campground facilities available, distance from parking areas and other improvements, vegetation and soil conditions, and points of interest.

Field Methods

Field methods consisted of: sketch maps of the campgrounds, inventory of units, and daily-use records.

Mapping.--A sketch map was drawn to show access and spur roads, and location of units, toilets, water outlets, parking areas, community shelters, fire circles, and other developments considered a part of the campground. The map was used to number and locate units to be observed and to show the relative placement of other facilities.

Unit Inventory.--An inventory describing the units was made during the first visit to the campground (fig. 5). It summarized conditions found with regard to shade, screening, ground cover, drainage, slope, erosion, and distances to various improvements. Size of clearing at each unit was indicated by measuring the maximum distance from the fire grate to the edge of the disturbed area caused by trampling or other activities that tended to alter or destroy the ground cover.

Daily Use Record.--Use of each unit was continuously recorded throughout the periods of observation (fig. 6). The record included the times of use and nonuse, number, age and sex of users, equipment used by visitors, apparent activities of users, and the State from which they came (from auto license plates). Summaries of the records provided a pattern of use for the campground as a whole, either daily or for the total period.

During the latter part of May 1962, two of the campgrounds were observed to test procedures. An analysis of the information obtained indicated that the procedures were adequate to achieve the objectives of the study. Recording use was difficult only during the peak hours of the day. At those times observations were recorded every other hour.

Figure 4.--
Boating, fishing, water skiing, and swimming at Sheridan Lake are main attractions for visitors using the Sheridan Point campground near Hill City, South Dakota, in the Black Hills National Forest. Nearby is the Mount Rushmore National Memorial.

Elevation ____________
Vegetation Zone ________

Unit No. ___________
Observer ___________
Date ___________

UNIT INVENTORY

Recreation Site ______________________ (Name and Number)
Type of Unit ______________________ (Camping, Trailer, Etc.)

Insolation at Unit

Shade present from 10 a.m. to 3 p.m.: Yes _____ No _____
If "Yes" show: Full _____ or Partial _____
Canopy: Under 10 ft. _____ 10-30 ft. _____ Over 30 ft. _____
Timber Type: Coniferous _____ Deciduous _____ Species _____________
Screened from adjacent unit: Yes _____ No _____

Ground Condition at Unit

Soil Surface: Stony _____ Sandy _____ Clay-Silt _____
Ground Cover: Grass _____ Weed _____ Shrub _____ Litter _____ Bare _____ Eroded _____
Surface Drainage: Good _____ Fair _____ Poor _____
Surface Slope: Level _____ 0-5% _____ 6-10% _____ 10%+ _____
Reinforcement: None _____ Concrete _____ Macadam _____ Gravel _____
Sand _____ Wood chips _____ Other _____
Maximum radius of disturbance _____ feet

Ground Condition Between Units

Canopy: Open _____ Dense _____
Soil Surface: Stony _____ Sandy _____ Clay-Silt _____
Ground Cover: Grass _____ Weed _____ Shrub _____ Litter _____ Bare _____ Eroded _____
Surface Drainage: Good _____ Fair _____ Poor _____
Surface Slope: Level _____ 0-5% _____ 6-10% _____ 10%+ _____

Facilities From Unit

Distance: Feet	0-50	50-100	100-150	150-200	200+
Closest parking area					
Toilet (men)					
Toilet (women)					
Garbage disposal					
Drinking water					
Closest-like facility					
Boat dock					
Fishing point					
Viewpoint					
Stream					
Trail					
____________					
____________					

Additional Characteristics

____

____

____

Figure 5.--Form used to inventory each family unit during observer's first visit to each campground.

Unit No. ____________
Observer ____________
Date ____________

DAILY USE RECORD

Recreation Site ____________________
(Name and Number)

Type of Unit ____________________
(Camping, Trailer, etc.)

Weather: Clear ____ Cloudy ____ Rain ____ Cold ____ Warm ____

		Age and Sex of Users Number												Equipment Used - Number									Activity							Remarks
		13 or less		14-20		21-39		40-59		60 plus		Tot.																		(license plate number, care of fires, breaking or establishing camp, clean or dirty camp)
Time	Total in party	M	F	M	F	M	F	M	F	M	F	M	F	Car or truck	Camper	Tr. Trailer	Cargo Trailer	Boat Trailer	Tent Trailer	Other sleep in vehicle	Tent	Bedroll	General enjoyment	Group activities	Camping	Picnicking	Fishing	Boating	Hiking	
6AM																														
7																														
8																														
9																														
10																														
11																														
12N																														
1																														
2																														
3																														
4																														
5																														
6																														
7																														
8PM																														

Present Conditions at Unit

Trampling: Severe ________ Not Severe ________
Soil Surface: Bare ________ Not Bare ________ Dusty: Yes _____ No _____

Vegetation Damage: Trees: Yes _____ No _____
Kind ____________
Understory: Yes _____ No _____
Kind ____________

Figure 6.--Form used to continuously record use of each unit at each campground throughout both observation periods.

Evaluation of Data

The initial compilation contained a summary of the daily use for each campground. These summaries provided information as to who used the campground, how long, camping equipment used, in- and out-State residents, and apparent activity. Individual campground summaries were combined to show the variation in origin, age classes, duration of stay, camping equipment used, and unit use. The intensity of use of units (indicated by their continuous occupancy) was related to distance from toilets, water outlets, closest unit, and nearest fishing point (from unit inventory).

Because the majority of the visitors combine activities, they were grouped under two major categories: camping and day-use. Camping involved overnight use, and might or might not include fishing, hiking, and other activities. Day-use involved no overnight use, and included picnicking, fishing, hiking, and general enjoyment, in combination or singly.

The number of parties as well as the total visitors in a party varied from unit to unit and from campground to campground. Accordingly, an item of measurement was devised to indicate the intensity of use for each unit. This was termed "average hours of daily use per visitor" and was calculated as follows:

> For camping, the time involved during an observational period was 81 hours, or 3.4 24-hour days. For each unit used for camping, the period total visitor hours was divided by the total number of visitors. This resulted in the average hours each visitor stayed when camping. The average hours per visitor was divided by 3.4 to obtain the average hours of daily use per visitor.
>
> For day-use, the time involved during an observational period was 46 daylight hours or 3.8 12-hour days. For each unit used for day-use, the period total visitor hours was divided by the total number of visitors, yielding the average hours each day-use visitor stayed. The average hours per visitor was divided by 3.8 to obtain the average hours of daily use per visitor.
>
> The average hours of daily use per visitor for camping and day-use were totaled to give a span of unit use of from 0 to 24 hours. Thus, a unit with an index of 24 hours (actually 23.8 hours due to rounding numbers) would be considered continually occupied and receiving a high intensity of use.
>
> For each campground, the average hours of daily use per visitor per unit was determined by totaling the average hours of daily use per visitor at each family unit and dividing by the number of units.

The Chi-square test (Snedecor, 1956) was employed to evaluate the preference of visitors for camping units as related to distances of units from parking areas, toilets, water outlets, fishing points, and closest unit, and to the size of clearing at the units. The results are only suggestive since computation of hypothetical frequencies based on numbers of units in each category leaves much to be desired. Consequently, the outcome of any statistical test may be solely a reflection of campground construction or layout and not of visitor preference.

RESULTS

The results of the study are combined into two periods. The first period includes the observations made from mid-June to the end of July; the second period, those made from the first of August to mid-September.

For comparative purposes the results are presented according to origin of visitors, camping equipment used, age classes, length of stay, and unit use. Where appropriate, reference is made to the implications of Chi-square tests as a means of isolating some of the factors associated with recreational use.

Origin of Visitors

A summary of the origin of parties by family units during two 4-day periods (table 2,a) reveals that in-State parties visiting the 12 campgrounds were more numerous than out-State.

Table 2.--Recorded use of 12 campgrounds in 5 States for two 4-day periods, 1962

Recorded use of campground	Arizona			New Mexico			Colorado				Wyoming	South Dakota	Total or average
	Rose Canyon	Lakeside	Ashurst	Fourth of July	Holy Ghost	La Sombra-Capulin	Maroon Lake	Echo Lake	Walton Creek	Chambers Lake	Mirror Lake	Sheridan Point	
FAMILY UNITS (No.)	[1] 85	51	50	26	22	17	61	19	14	55	19	96	514
ORIGIN OF PARTIES (No.):													
First period--													
Camping[2]													
In-State	59	75	43	1	16	6	53	10	11	47	2	42	365
Out-State	8	26	2	0	10	11	45	10	40	9	2	124	287
Day-use[3]													
In-State	134	22	34	20	19	31	43	50	25	67	22	11	478
Out-State	14	5	0	0	2	25	17	13	41	9	6	5	137
Total	215	128	79	21	47	73	158	83	117	132	32	182	1,267
Second period--													
Camping[2]													
In-State	109	67	35	0	15	3	54	19	12	75	1	16	406
Out-State	10	17	2	1	29	24	57	16	10	25	10	18	219
Day-use[3]													
In-State	145	22	22	2	18	22	34	49	24	55	22	4	419
Out-State	13	3	2	1	6	16	10	20	25	8	16	1	121
Total	277	109	61	4	68	65	155	104	71	163	49	39	1,165
CAMPING EQUIPMENT USED (No.):													
First period--													
Cars	291	125	86	27	60	87	182	89	110	118	36	184	1,395
Campers	11	22	13	1	4	2	10	3	12	33	0	15	126
Travel trailers	15	53	14	0	13	7	33	4	24	13	0	107	283
Boat trailers	0	3	13	0	0	0	0	0	0	9	0	8	33
Tents	43	45	21	1	25	7	61	5	17	38	5	64	332
Bedrolls[4]	44	7	3	0	2	22	3	0	2	6	0	0	89
Second period--													
Cars	405	107	72	4	73	81	158	115	79	162	50	21	1,327
Campers	18	20	15	0	7	6	19	6	7	25	3	8	134
Travel trailers	34	38	14	0	18	10	16	5	10	36	4	25	210
Boat trailers	0	1	11	0	0	0	0	1	0	9	0	6	28
Tents	85	39	20	1	36	10	95	25	7	63	2	5	388
Bedrolls[4]	64	0	12	0	7	3	20	0	0	6	0	0	112
VEHICLES (No.):													
First period--													
Vehicles	302	147	99	28	64	89	192	92	122	151	36	199	1,521
Vehicles per unit (average)	3.6	2.9	2.0	1.1	2.9	5.2	3.1	4.8	8.7	2.7	1.9	2.1	3.0
Second period--													
Vehicles	423	127	87	4	80	87	177	121	86	187	53	29	1,461
Vehicles per unit (average)	5.0	2.5	1.7	0.2	3.6	5.1	2.9	6.4	6.1	3.4	2.8	0.3	2.8
VISITORS PER PARTY (Average No.):													
First period--													
Camping[2]	5.8	3.8	3.3	6.0	5.8	4.8	4.4	4.3	4.0	4.1	3.5	4.6	4.5
Day-use[3]	6.1	4.5	4.3	7.0	6.5	6.4	4.2	5.1	4.2	5.0	5.1	4.5	5.2
Total	6.0	4.0	3.7	6.9	6.1	6.0	4.3	4.9	4.1	4.6	4.9	4.6	5.0
Second period--													
Camping[2]	6.7	3.8	4.3	5.0	5.8	4.0	4.6	5.6	3.7	4.3	3.7	2.5	4.5
Day-use[3]	6.1	4.0	5.5	5.0	4.6	6.4	3.7	6.0	4.3	4.5	4.9	2.8	4.8
Total	6.4	3.9	4.8	5.0	5.4	5.4	4.3	5.9	4.1	4.4	4.7	2.6	4.7

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[1] Only 84 units in compiled data; records incomplete for one unit.

[2] Overnight use; may or may not include fishing, hiking, and other activities.

[3] No overnight use; includes picnicking, fishing, general enjoyment, hiking, in combination or singly.

[4] Without other cover.

Table 2.--Recorded use of 12 campgrounds in 5 States for two 4-day periods, 1962 (continued)

Recorded use of campground	Arizona			New Mexico			Colorado				Wyoming	South Dakota	Total or average
	Rose Canyon	Lakeside	Ashurst	Fourth of July	Holy Ghost	La Sombra-Capulin	Maroon Lake	Echo Lake	Walton Creek	Chambers Lake	Mirror Lake	Sheridan Point	
[e] VISITORS PER VEHICLE (Average No.):													
First period--													
Camping[2]	3.8	3.3	2.8	6.0	4.1	3.8	3.7	3.8	3.7	3.4	3.5	4.0	3.
Day-use[3]	4.3	3.7	3.2	5.2	4.5	5.1	4.0	4.3	4.1	4.4	4.1	3.5	4.
Total	4.1	3.4	3.0	5.2	4.3	4.8	3.8	4.2	3.9	3.9	4.1	3.9	4.
Second period--													
Camping[2]	4.0	3.0	3.3	5.0	4.5	3.1	3.6	4.3	3.3	3.7	3.4	2.4	3.
Day-use[3]	4.2	4.2	3.2	5.0	4.4	4.7	3.6	4.9	3.4	3.7	4.6	2.8	4.
Total	4.1	3.3	3.3	5.0	4.5	4.1	3.6	4.7	3.4	3.7	4.3	2.5	3.
[f] AGE CLASSES, CAMPING VISITORS (No.):													
First period--													
13 yrs. or less	146	118	30	4	58	33	147	29	67	71	6	303	1,012
14-20 yrs.	48	26	8	0	6	5	36	6	22	22	0	67	246
21-39 yrs.	115	90	41	2	50	31	147	28	53	90	4	197	848
40-59 yrs.	55	112	54	0	24	12	74	18	45	24	4	140	562
60+ yrs.	1	31	16	0	2	0	11	0	10	19	0	18	108
Total	365	377	149	6	140	81	415	81	197	226	14	725	2,776
Second period--													
13 yrs. or less	305	94	46	2	115	29	177	66	33	133	8	12	1,020
14-20 yrs.	53	23	9	1	18	11	31	27	3	53	6	0	235
21-39 yrs.	255	67	55	2	89	30	183	56	33	148	12	12	942
40-59 yrs.	165	116	43	0	33	33	79	24	10	73	14	26	616
60+ yrs.	3	14	6	0	0	0	10	1	3	15	1	8	61
Total	781	314	159	5	255	103	480	174	82	422	41	58	2,874
[g] AGE CLASSES, DAY-USERS (No.):													
First period--													
13 yrs. or less	252	43	44	64	62	126	59	88	92	90	31	25	976
14-20 yrs.	100	3	8	7	14	34	[5] 144	30	39	29	23	1	432
21-39 yrs.	379	39	51	44	43	121	77	131	63	178	39	29	1,194
40-59 yrs.	141	34	40	25	17	57	66	53	69	63	30	8	603
60+ yrs.	12	2	4	0	0	9	31	7	18	8	10	0	101
Total	884	121	147	140	136	347	377	309	281	368	133	63	3,306
Second period--													
13 yrs. or less	641	32	42	9	35	107	40	124	52	66	55	5	1,208
14-20 yrs.	119	7	13	0	10	19	16	30	30	16	18	1	279
21-39 yrs.	631	30	43	6	42	88	55	150	47	104	61	4	1,261
40-59 yrs.	330	31	19	0	18	40	34	72	64	72	33	4	717
60+ yrs.	11	1	10	0	1	1	11	25	18	19	21	0	118
Total	1,732	101	127	15	106	255	156	401	211	277	188	14	3,583
[AVERAGE DAILY USE PER UNIT (Visitor hours):													
First period--													
Camping[2]	33	70	31	2	62	30	54	22	56	27	10	72	39
Day-use[3]	10	1	3	4	5	11	3	8	7	4	5	0.5	5
Total	43	71	34	6	67	41	57	30	63	31	15	72	44
Second period--													
Camping[2]	93	67	30	1	107	41	71	70	27	58	14	5	49
Day-use[3]	11	1	1	0.2	3	10	1	10	7	3	6	0.1	4
Total	104	68	31	1	110	51	72	80	34	61	20	5	53

Includes a music group of 130 from Aspen, Colorado.

Table 2.--Recorded use of 12 campgrounds in 5 States for two 4-day periods, 1962 (continued)

Recorded use of campground	Arizona			New Mexico			Colorado				Wyoming	South Dakota	Total or average
	Rose Canyon	Lakeside	Ashurst	Fourth of July	Holy Ghost	La Sombra-Capulin	Maroon Lake	Echo Lake	Walton Creek	Chambers Lake	Mirror Lake	Sheridan Point	
[i] AVERAGE LENGTH OF STAY PER VISITOR (Hours):													
First period--													
Camping[2]	25.8	32.3	35.3	23.0	32.9	21.7	27.1	17.8	13.4	22.4	44.6	32.2	27.4
Day[3]	3.6	2.1	4.2	3.0	3.1	2.0	2.0	1.8	1.4	2.1	2.6	2.7	2.5
Total	10.1	25.0	19.8	3.8	18.2	5.7	15.2	5.1	6.3	9.8	6.6	29.9	12.9
Second period--													
Camping[2]	34.1	36.9	32.3	23.0	31.4	22.9	30.8	26.1	15.7	25.7	22.3	26.6	27.3
Day[3]	3.9	2.8	2.0	1.5	2.7	2.5	1.7	1.8	1.8	2.4	2.2	1.8	2.2
Total	12.1	28.6	18.8	6.8	23.0	8.3	23.6	9.1	5.7	16.5	5.8	21.7	15.0
[j] OFF-UNIT USE[6] (No.):													
First period--													
Cars	92	--	165	13	47	30	145	83	19	92	51	14	751
Origin:													
In-State	72	--	--	4	29	12	--	--	--	--	--	--	117
Out-State	16	--	--	8	9	17	--	--	--	--	--	--	50
Visitors	310	--	399	46	190	103	551	374	70	350	210	53	2,656
Visitor hours[7]	404	--	--	7	2,017	229	--	--	--	--	--	--	2,657
Second period--													
Cars	390	66	274	8	93	45	142	29	12	79	76	21	1,235
Origin:													
In-State	322	53	251	8	36	31	--	--	--	--	--	--	701
Out-State	22	8	11	0	45	11	--	--	--	--	--	--	97
Visitors	1,140	177	794	25	392	127	539	131	44	300	318	80	4,067
Visitor hours[7]	8,526	2,039	6,196	5	4,282	251	--	--	--	--	--	--	21,299
[k] DAILY USE PER CAMPING VISITOR, ALL UNITS (Percent):													
First period--													
0- 6 hours	74	27	54	100	64	71	54	84	100	74	80	50	62
7-12 hours	21	31	24	0	18	23	36	16	0	24	15	26	23
13-18 hours	5	16	2	0	9	6	5	0	0	2	5	4	5
19-24 hours	0	26	20	0	9	0	5	0	0	0	0	20	10
Second period--													
0- 6 hours	33	31	60	100	18	53	38	63	86	56	84	91	57
7-12 hours	27	20	22	0	68	35	40	32	7	38	16	7	25
13-18 hours	24	8	6	0	9	6	11	0	0	2	0	2	8
19-24 hours	16	41	12	0	5	6	11	5	7	4	0	0	10
[m] DAILY USE PER VISITOR, PER UNIT (Hours):													
First period--													
Camping[2]	4.9	12.2	8.2	0.3	6.7	4.5	6.9	3.2	4.0	4.4	2.8	9.5	5.6
Day-use[3]	.7	.2	.4	.4	.4	.6	.3	.3	.4	.4	.3	.1	.4
Total	5.6	12.4	8.6	.7	7.1	5.1	7.2	3.5	4.4	4.8	3.1	9.6	6.0
Second period--													
Camping[2]	11.3	13.8	6.5	.25	9.2	6.8	9.4	6.7	5.1	7.0	2.8	1.3	6.7
Day-use[3]	.7	.2	.1	.05	.4	.4	.2	.4	.4	.4	.4	0	.3
Total	12.0	14.0	6.6	.3	9.6	7.2	9.6	7.1	5.5	7.4	3.2	1.3	7.0

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[6] Those who entered a campground but did not use a designated family unit; includes camping, day use, driving in and out.

[7] Excludes time driving in and out.

Camping parties outnumbered day-use parties by a very narrow margin (1.1 to 1.0). The individual campgrounds show a wide variation between camping and day-use parties, and between in- and out-State parties for the two periods.

The significance of these differences appears to lie in the distance the campgrounds are from major population centers, proximity of principal travel routes, and presence of outstanding points of interest. For example, the high proportion of in-State day-users at Rose Canyon, Fourth of July, Echo Lake, and Mirror Lake campgrounds reflects their closeness to Tucson, Arizona, Albuquerque, New Mexico, Denver, Colorado, and Laramie, Wyoming; the high ratio of out-State camping and day-use parties at Walton Creek and La Sombra-Capulin campgrounds reflects their proximity to major travel routes--U. S. Highways 40 and 64. The high number of both in- and out-State camping parties at Holy Ghost, Maroon Lake, and Sheridan Point campgrounds indicates interest in major points of interest such as the Pecos Wilderness Area, the Maroon Bells-Snowmass Wild Area, and Mount Rushmore in the Black Hills. The high proportion of in-State camping and day-users at Lakeside, Ashurst, and Chambers Lake campgrounds reflects interest primarily in fishing and boating.

Camping Equipment

As expected, the major unit of transportation was the automobile (table 2,b). Less than 10 percent of the total vehicles consisted of campers (pickup with camper-back, fig. 7, or other sleep-in vehicle). The use of tents (fig. 8) for camping exceeded travel trailers (fig. 9) by a ratio of 1.5 to 1. The number of boat trailers at family units was small since most of them were stored at boat launching areas. Bedrolls, without other cover, were common and were used mainly by organized groups in transit.

Number of Vehicles

A significant finding was the number of vehicles driven to units at individual campgrounds during the two 4-day observational periods (table 2,c). The higher the average number of vehicles per unit the greater the pressure of vehicular use at the campground. One vehicle daily per unit or four for a period would be the normal expectation.

Number of Visitors

The average number of visitors per party (table 2,d) is generally greater than the average number of visitors per vehicle (cars plus campers, table 2,e) because frequently two or more vehicles are used by a single party. Both visitors per party and visitors per vehicle vary from one campground to another, and from one period to the next. Camping visitors per party and per vehicle are less in number than day-use visitors per party and per vehicle.

Age Classes

The age classes of visitors[5] for all campgrounds studied during both observational periods followed a consistent pattern:

Period of observation and age of visitors	Camp	Day	Total
	(percent)		
First period:			
13 yrs. or less	36	29	33
14-20 yrs.	10	13	11
21-39 yrs.	30	36	33
40-59 yrs.	20	19	19
60+ yrs.	4	3	4
Second period:			
13 yrs. or less	35	34	34
14-20 yrs.	9	8	8
21-39 yrs.	33	35	34
40-59 yrs.	21	20	21
60+ yrs.	2	3	3

The young adult (21-39 years) and children (13 years or less) were the dominant visitors. Next in importance was the middle-aged adult (40-59 years) followed by the teenager (14-20 years). The older adult (60+ years) was the most infrequent visitor.

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[5] *Since age of visitors was estimated, there is an inherent error in the data.*

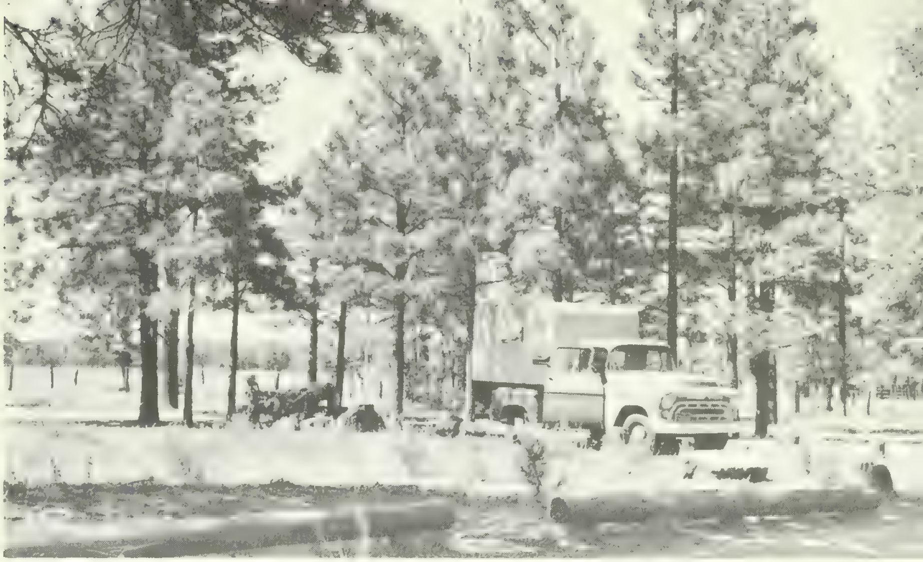


Figure 7.--Campers are used by 3 out of 20 visitors who camp. This unit at Lakeside campground received high use. Sitgreaves National Forest, Arizona.

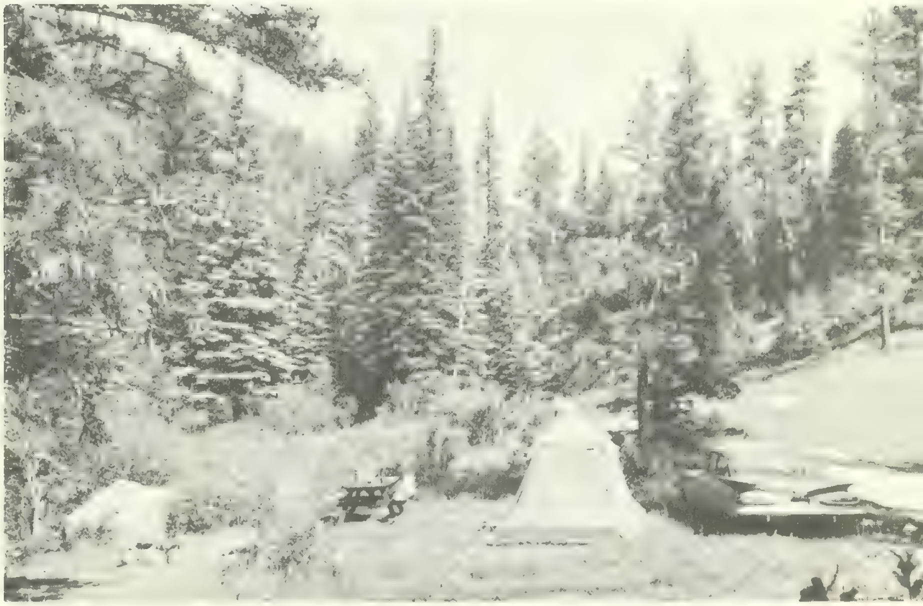


Figure 8.--Tents are popular with 4 out of 10 visitors who camp. Holy Ghost campground, Santa Fe National Forest, New Mexico.

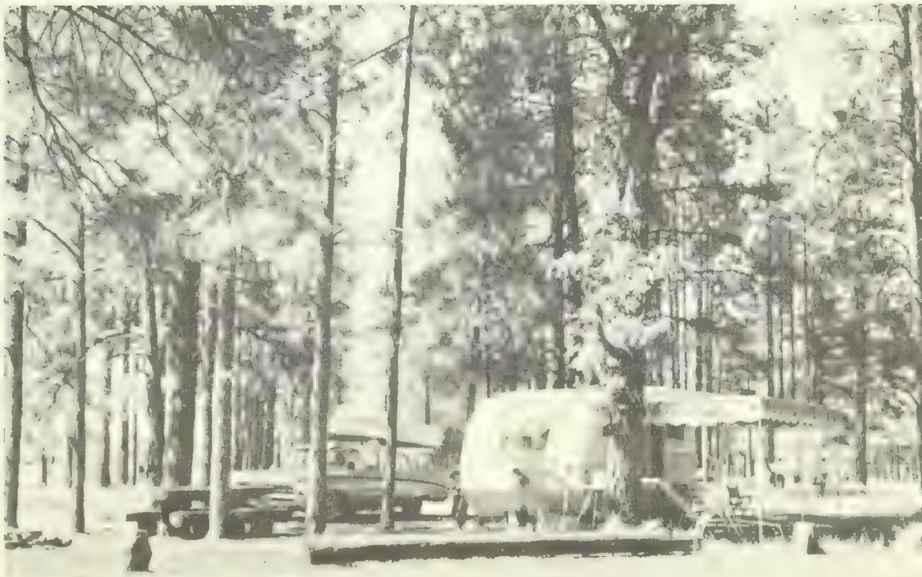


Figure 9.--Travel trailers are used by 3 out of 10 visitors who camp. This unit at Lakeside campground also received high use. Sitgreaves National Forest, Arizona.

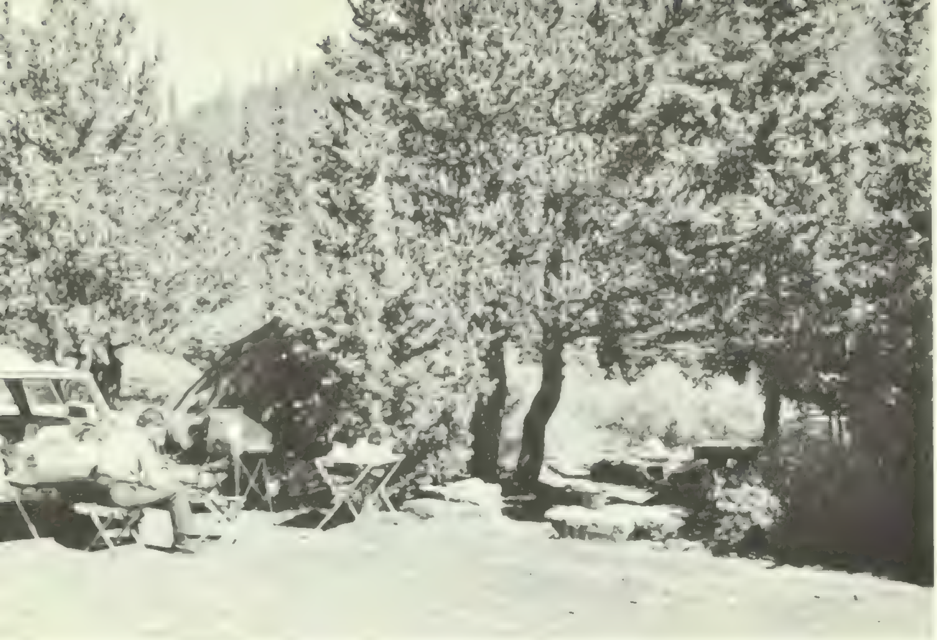


Figure 10.--Off-unit use in access road at Echo Lake campground; unit table to right. Arapaho National Forest, Colorado.

The young adults and children together often consisted of a party of 3 to 5, but just as often groups of 25 or more children under the supervision of 2 to 4 young adults visited the campgrounds. Members of the Boy Scouts, Girl Scouts, Future Farmers of America, 4-H, Dude Ranch, and church organizations made up these groups.

The same general age-class pattern held for the individual campgrounds with regard to camping (table 2,f) and day-use (table 2,g).

Relief from desert heat and good fishing opportunities tended to attract a larger proportion of middle-aged and older adults, both for camping and day-use, to the Lakeside and Ashurst campgrounds than to the others studied in Arizona and New Mexico. Likewise, the scenic attractions and good fishing at Mirror Lake campground in Wyoming attracted a greater number of this group for camping and day-use. The middle-aged and older adults constituted a larger proportion of the day-users at Maroon Lake and Walton Creek campgrounds than at the other campgrounds in Colorado and South Dakota. The scenic attractions nearby, as well as convenience for noon-day stops, may account for the greater visits by this group.

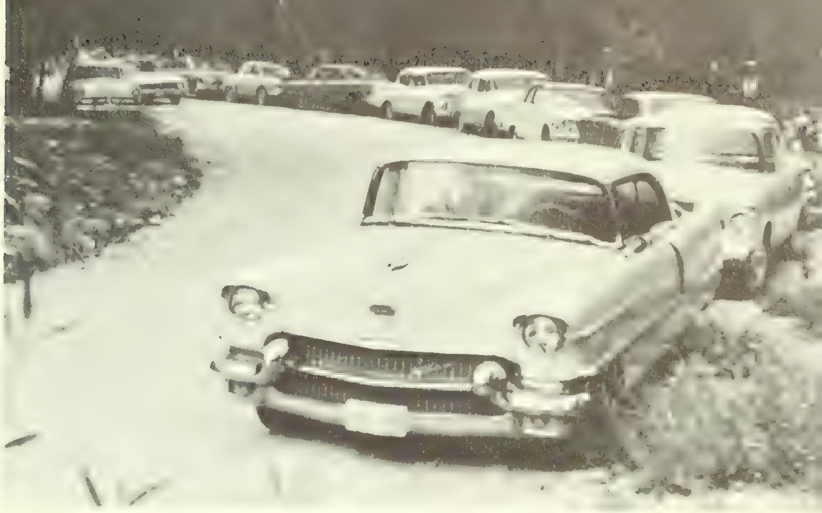
The sex ratio of visitors for both periods to all campgrounds was 51.5 percent males, 48.5 percent females. These data suggest a higher participation by females in summer forest recreation than previously suspected.

Visitor-hour Use

Visitor-hour use--the basic unit in measuring use of recreation facilities--is the product of the number of visitors times the hours they occupied a family unit. A visitor to a unit was counted only once during his stay. Most visitor-hour use was attributed to camping and not day-use (table 2,h). An exception was the Fourth of July campground, which received more visitor-hour use in the first period through day-use than through camping. In general, day-use was only about 10 percent of the visitor-hour use at the campgrounds.

Previous discussion has indicated that the use of the 12 campgrounds reflects the distance they are from major population centers, the proximity of travel routes, and points of interest. The average daily visitor-hour use per unit at each campground is a measure of this use. Had the average party of 4.8 visitors (table 2,d) used a unit for 24 hours, the visitor-hour use would be 115. Using this as a base, units at the campgrounds were used on the average of 38 percent during the first period and 46 percent during the second. Only in the cases of Rose Canyon over Labor Day weekend, and Holy Ghost where large groups stayed longer in the second period were the

Figure 11.--Parking along access roads caused traffic congestion such as this at Rose Canyon campground. Coronado National Forest, Arizona.



units used near the maximum. Of particular interest is the lack of use at Fourth of July campground, and the almost nonuse of Sheridan Point campground after Labor Day.

Length of Stay

Length of stay (table 2,i) is expressed in hours per visitor, and is obtained by dividing total visitor hours at all units by total visitors. Hours of stay per visitor corrects for the varying numbers of parties and visitors per party.

The length of stay per visitor at each of the campgrounds was variable, particularly for camping. It was somewhat more uniform for day-users. If all visitors to a campground had stayed through the full observation period, then the length of stay per visitor would have been 81 hours. As it was, all visitors averaged only 13 to 15 hours per person during an observational period. For both camping and day-use, the time spent per visitor at a campground was short.

Off-unit Use

Off-unit use (table 2,j) includes camping and day-use at the campground but not at designated family units (fig. 10). It also includes driving in and out--a visit of less than 15 minutes' duration.

The magnitude of off-unit use may be attributed to several interacting factors: fishing opportunities at Rose Canyon, Ashurst, and Chambers Lake campgrounds; scenic attractions at Maroon Lake and Mirror Lake campgrounds; establishment of organization camps at the Holy Ghost campground; or the desire to see "what's going on" as in the case of the Lakeside and La Sombra-Capulin campgrounds.

The cars of off-unit users place an additional burden on access roads, disturb family-unit users by creating dust palls, and cause hazardous traffic congestions (fig. 11).

Daily Use of Family Units

"Average hours of daily use per visitor" may range from 0 to 24, as defined on page 10. This term was devised to measure intensity of use of the units within a campground. Throughout the 12 campgrounds observed, intensity of use was not uniform (table 2,k). For example, over the two 4-day periods, 60 percent of the units averaged less than 6 hours of daily use per camping visitor. Day-use of units did not exceed 6 hours (table 2,i); thus, all units receiving day-use alone were used less than 6 hours per visitor.

Certain campgrounds, notably Rose Canyon (second period), and Lakeside, Ashurst, Maroon Lake, and Sheridan Point (first period) had several family units that received up to 24 hours' use per day per camping visitor (fig. 12). All of the units at Fourth of July and Walton Creek (first period) campgrounds were used 6 hours or less per day per camping visitor (table 2,k). Some of the factors associated with this apparent disparity of unit use will be discussed in a later section.

Table 3.--Choice of family units by incoming new parties[1] to 12 campgrounds in 5 States for two 4-day periods, 1962

Choice of units	Arizona			New Mexico			Colorado				Wyoming	South Dakota	Total or average
	Rose Canyon	Lakeside	Ashurst	Fourth of July	Holy Ghost	La Sombra-Capulin	Maroon Lake	Echo Lake	Walton Creek	Chambers Lake	Mirror Lake	Sheridan Point	
FAMILY UNITS (No.)	[2] 85	51	50	26	22	17	61	19	14	55	19	96	514
[a] UNITS SELECTED (No. of units):													
First period --													
No. of new parties:													
0	10	16	18	10	3	1	12	2	0	14	10	40	136
1-2	38	19	21	15	14	4	25	5	0	19	3	40	203
3-4	26	14	11	1	4	7	19	5	3	14	5	15	124
5-6	9	1	0	0	1	3	4	2	4	7	0	1	32
7+	1	1	0	0	0	2	1	5	7	1	1	0	19
Second period--													
No. of new parties:													
0	11	23	26	22	2	4	12	0	1	3	6	84	194
1-2	29	18	17	4	10	4	33	5	6	23	6	12	167
3-4	24	6	7	0	9	4	12	5	1	25	2	0	95
5-6	14	3	0	0	1	3	4	3	3	4	3	0	38
7+	6	1	0	0	0	2	0	6	3	0	2	0	20
[b] UNITS NOT SELECTED (No. of units):													
First period--													
Constantly used[3]	0	13	10	0	2	0	3	0	0	0	0	20	48
Never used	10	3	8	10	1	1	9	2	0	14	10	20	88
Not selected	10	16	18	10	3	1	12	2	0	14	10	40	136
Second period--													
Constantly used[3]	[4] 11	21	6	0	1	1	7	[5] 0	1	2	0	0	50
Never used	0	2	20	22	1	3	5	0	0	1	6	84	144
Not selected	11	23	26	22	2	4	12	0	1	3	6	84	194

[1] Those that actually came to a campground during the observational periods, in addition to parties present when period began.
[2] Only 84 units in compiled data; records incomplete for one unit.
[3] Units used 19 to 24 hours.
[4] Two units not used full 24 hours; they were selected by incoming new parties.
[5] One unit not used full 24 hours; it was selected by incoming new party.

In general, the average daily use per visitor per family unit for both camping and day-use averaged 6 hours the first period and 7 the second (table 2,m). The average daily use per day-use visitor at each family unit was brief--from 0.3 to 0.4 hour (20-25 minutes). With the exception of the Fourth of July campground (first period), the bulk of the average hours of daily use per visitor at each unit was contributed by visitors who camped.

Incoming New Parties

Incoming new parties--those that actually came to a campground during the observational periods, in addition to those parties already present when the period began--were recorded and identified with the family units they selected for use (table 3). The number of incoming new parties selecting a particular family unit was used as a measure of the popularity of that unit, provided that it was not continuously occupied.

Ten percent of the family units were used between 19 and 24 hours (table 2,k). This percentage influenced the number of family units available to be chosen by new parties (table 3,a). Some units could not be chosen because they were in constant use; others were never selected although available (table 3,b). In the first period 17 percent of the 514 family units were never used; 28 percent were never used

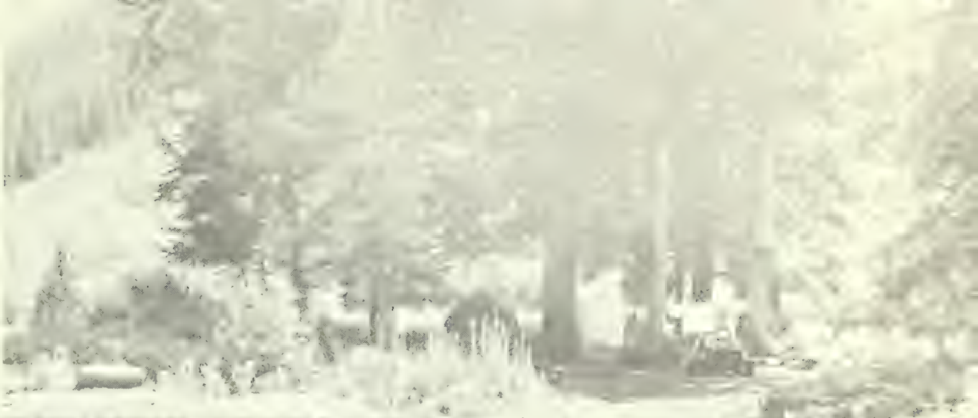


Figure 12.--This unit at Maroon Lake campground, designed for both camping and day-use, was used constantly during a 4-day observational period. White River National Forest, Colorado.

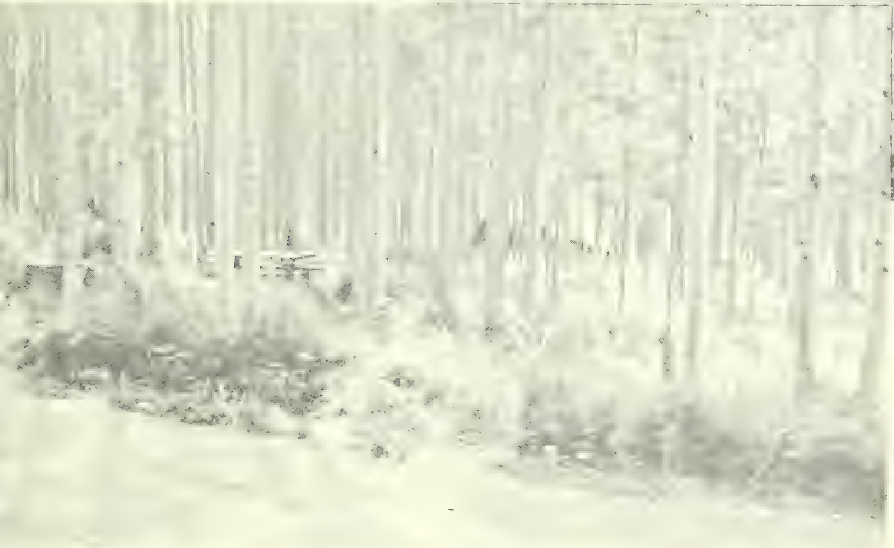


Figure 13.--This unit restricted to day-use at Maroon Lake campground was never used during either period. Its companion (background) was used for both camping and day-use. White River National Forest, Colorado.

in the second period (fig. 13). The scope of the present study did not provide for personal interviews with visitors; reasons why some units were not selected are probably related to the associated factors which follow.

More important is the observation that a limited number of family units are selected by several new parties (fig. 14). For example, in the first period, 10 percent of the total family units (514) were selected by 5 or more incoming new parties; this percentage was about the same (11 percent) during the second period.

It would appear that the parties visiting the campgrounds could have been accommodated by about 20 percent fewer family units, since these units were not selected for use during the two observational periods.

There is a rapid turnover of certain family units and not of others. This may be more related to day-users whose visits are brief than to an undesirable camping environment.

Factors Associated with Use

Chi-square tests of probability were used (Snedecor, 1956) to identify factors that might be associated with the total hours of daily use per visitor at each family unit. Because of the individual campground differences with regard to number of family units, topography, distance from population centers, and opportunities for different recreational activities, it was decided to combine recreational use by periods for testing purposes. No tests were made of the presence or absence of such factors as shade or screening because the bulk of the family units at each campground were usually either one way or the other. Characteristics of each campground were inventoried, however, during the first period of observation (table 4,a). Dispersion of family

Table 1 --Physical characteristics of family units at each of 12 campgrounds in 5 States, inventoried or measured during first 4-day observation period, 1962

Inventory or measurement	Arizona			New Mexico			Colorado				Wyoming	South Dakota	Total or average
	Rose Canyon	Lakeside	Ashurst	Fourth of July	Holy Ghost	La Sombra-Capulin	Maroon Lake	Echo Lake	Walton Creek	Chambers Lake	Mirror Lake	Sheridan Point	
[a] CHARACTERISTICS INVENTORIED (No. of units):													
Shade --													
Yes	66	50	50	14	17	13	48	13	10	49	8	86	424
No	18	1	0	12	5	4	13	6	4	6	11	10	90
Screened --													
Yes	40	0	1	5	5	10	13	10	0	8	1	0	93
No	44	51	49	21	17	7	48	9	14	47	18	96	421
Stony surface --													
Yes	8	1	49	0	7	0	5	0	0	9	16	0	95
No	76	50	1	26	15	17	56	19	14	46	3	96	419
Bare surface --													
Yes	80	16	12	11	11	11	0	3	0	3	2	0	149
No	4	35	38	15	11	6	61	16	14	52	17	96	365
Eroded surface --													
Yes	13	7	12	0	16	9	6	14	7	0	17	11	112
No	71	44	38	26	6	8	55	5	7	55	2	85	402
Reinforced --													
Yes	60	1	0	26	0	0	2	1	1	55	0	5	151
No	24	50	50	0	22	17	59	18	13	0	19	91	363
[b] CLEARING RADIUS[1] (No. of units):													
0- 5 feet	0	15	39	8	6	4	[2] 3(1)	0	1	0	2	26	104
6-10 feet	0	13	6	12	3	3	20(11)	0	3	3	2	25	90
11-15 feet	7	14	2	2	5	3	26(21)	8	4	42	9	20	142
16-20 feet	40	4	3	4	5	3	4(12)	6	4	7	5	9	94
21-25 feet	21	4	0	0	2	2	2(7)	2	2	3	1	6	45
26-30 feet	10	1	0	0	1	1	5(6)	2	0	0	0	8	28
31-35 feet	1	0	0	0	0	1	0(1)	1	0	0	0	0	3
36-40 feet	5	0	0	0	0	0	1(2)	0	0	0	0	2	8
[b] DISTANCE FROM UNITS TO FACILITIES (No. of units):													
Parking --													
0- 50 feet	46	51	47	11	21	17	47	13	14	55	17	96	435
51-100 feet	21	0	3	13	1	0	5	3	0	0	1	0	47
101-150 feet	6	0	0	2	0	0	1	1	0	0	1	0	11
151-200 feet	6	0	0	0	0	0	6	1	0	0	0	0	13
201+ feet	5	0	0	0	0	0	2	1	0	0	0	0	[illegible]
Toilet --													
0- 50 feet	1	14	1	0	0	10	4	3	4	8	0	22	67
51-100 feet	16	19	2	11	7	2	18	10	4	8	1	36	134
101-150 feet	12	9	1	10	3	5	5	2	5	9	4	16	81
151-200 feet	10	4	2	5	3	0	9	3	0	7	0	17	60
201+ feet	45	5	44	0	9	0	25	1	1	23	14	5	172
Trash container --													
0- 50 feet	84	48	35	25	19	13	47	19	12	55	3	90	450
51-100 feet	0	3	9	1	1	4	7	0	1	0	7	6	39
101-150 feet	0	0	3	0	1	0	2	0	1	0	3	0	10
151-200 feet	0	0	3	0	0	0	5	0	0	0	0	0	8
201+ feet	0	0	0	0	1	0	0	0	0	0	6	0	7
Drinking water --													
0- 50 feet	3	20	0	3	0	2	12	8	9	10	0	15	82
51-100 feet	6	19	0	7	0	1	20	3	4	17	0	30	107
101-150 feet	3	8	0	3	0	0	8	6	1	8	0	10	47
151-200 feet	5	4	0	3	0	0	11	2	0	11	0	7	43
201+ feet	67	0	50	10	22	14	10	0	0	9	19	34	235
Closest unit --													
0- 50 feet	1	46	32	20	2	8	5	3	5	5	7	42	176
51-100 feet	28	5	16	6	7	7	36	12	8	22	9	52	208
101-150 feet	22	0	2	0	2	2	15	4	1	25	2	1	76
151-200 feet	26	0	0	0	4	0	5	0	0	3	1	0	39
201+ feet	7	0	0	0	7	0	0	0	0	0	0	1	15
Fishing point --													
0- 50 feet	0	0	7	0	11	17	8	0	7	12	2	4	68
51-100 feet	0	0	4	0	4	0	1	0	4	3	1	12	29
101-150 feet	0	0	9	0	3	0	2	0	3	3	2	4	26
151-200 feet	0	0	6	0	2	0	3	0	0	4	0	5	22
201+ feet	84	51	22	26	2	0	47	19	0	33	14	71	369

---

[1] Based on maximum distance from fire grate to edge of disturbed area created by trampling or other activities that tended to destroy the ground cover.

[2] Numbers in parentheses indicate remeasurement during the second observation period; not included in total.

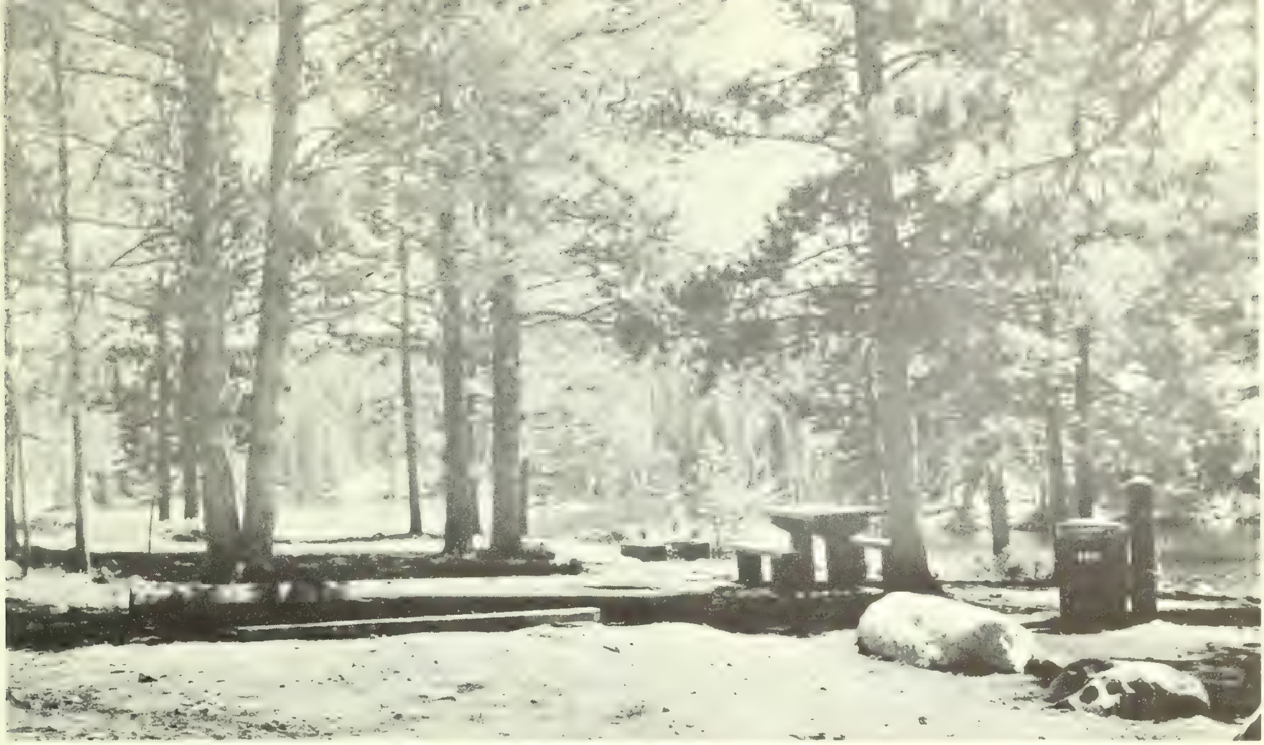


Figure 14.--This unit at Chambers Lake campground was selected by five or more incoming new parties during a 4-day observation period. Roosevelt National Forest, Colorado.

units was usually found according to the distance they were from parking, toilets, drinking water, closest unit, fishing point, and size of clearing. Those campgrounds with units sufficiently dispersed were then combined to test the total hours of daily use per visitor at each unit against distances to facilities (table 4,b). The tests indicate the following:

1. In the first period, family units within 100 feet of toilets were preferred over those located over 100 feet. In the second period, units within 50 feet of toilets were least preferred and those over 200 feet most preferred.

2. In the first period, family units within 150 feet of drinking water were used longer than those located over 150 feet. The same condition prevailed during the second period except the distance increased to 200 feet.

3. There was a tendency in the first period for family units located more than 150 feet apart to be used longer than those located closer together. In the second period, units closer than 100 feet were used less than those farther apart. (fig. 15).

4. In the first period, family units located from 50 to 200 feet from a fishing point were used longer than units located less than 50 feet or more than 200 feet. In the second period, family units less than 50 feet or between 100 and 150 feet from a fishing point were used longer than those located at other distances.

5. Family units with a clearing more than 20 feet in radius were used longer in the first period than those under 20 feet. In the second, those units with a clearing over 10 feet in radius were used longer than the units with less (fig. 16).

Calculations for Chi-square tests are shown (table 5). A more thorough test of experimentally laid-out campgrounds is needed, however, to ascertain the true relation between total hours of daily use per visitor at each unit and such factors as parking, toilets, drinking water, and size of clearing.

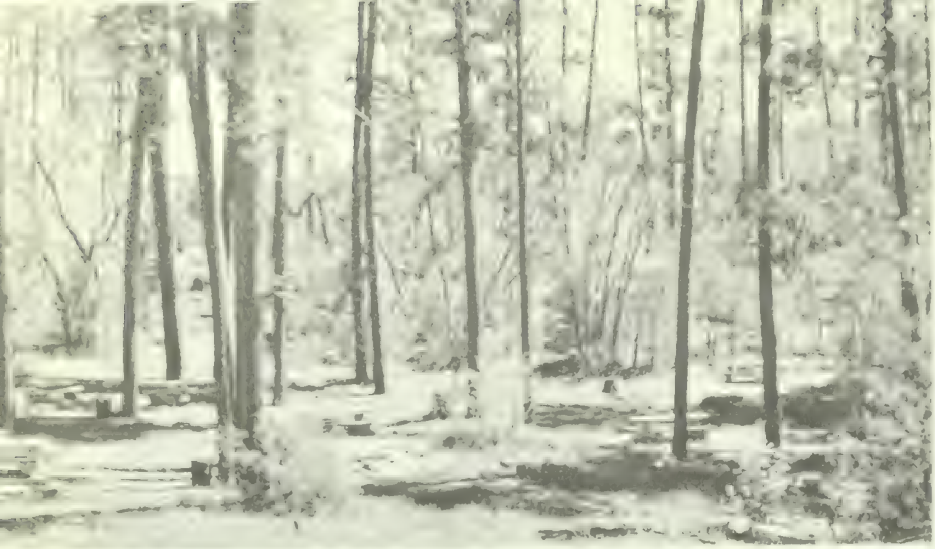


Figure 15.--Family units closer together than 100 feet are not used so long as those farther apart. Fourth of July campground. Cibola National Forest, New Mexico.

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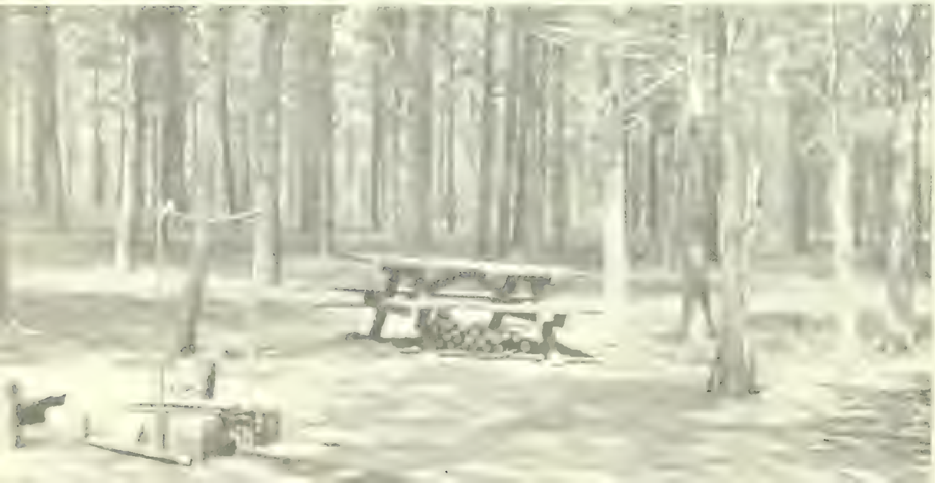

Figure 16.--Family units with a clearing over 10 feet in radius, such as this one at Sheridan Point campground, are used more than units with a smaller clearing. Black Hills National Forest, South Dakota.

Table 5.--Calculations of Chi-square tests of probability -- expected and observed use refer to "total hours of daily use per visitor at each family unit"

Distance and observation period	Number of units	Percent units	Expected use (E)	Observed use (O)	O E	(O - E)^2	$\frac{(O - E)^2}{E}$
TO TOILETS:							
First period--							
0- 50 feet	66	14.8	461.1	526.1	65.0	4,255.0	9.16
51-100 feet	131	29.4	916.0	998.6	82.6	6,822.76	7.45
101-150 feet	76	17.1	532.9	459.9	-73.0	5,329.0	10.0
151-200 feet	58	13.1	408.2	451.2	43.0	1,849.0	4.53
201+ feet	114	25.6	797.6	680.0	-117.6	13,829.76	17.34
Total	445	100.0	3,115.8	3,115.8	0		48.48 = X^2 **
Second period--							
0- 50 feet	66	14.8	502.5	437.7	-64.8	4,199.04	8.36
51-100 feet	131	29.4	998.2	1,002.7	4.5	20.25	--
101-150 feet	76	17.1	580.6	522.3	-58.3	3,398.89	5.85
151-200 feet	58	13.1	444.8	443.4	-1.4	1.96	--
201+ feet	114	25.6	869.2	989.2	120.0	14,400	16.57
Total	445	100.0	3,395.3	3,395.3	0		30.78 = X^2 **
TO DRINKING WATER:							
First period--							
0- 50 feet	68	22.1	517.0	589.8	72.8	5,299.84	10.25
51-100 feet	96	31.2	729.9	816.7	86.8	7,534.24	10.32
101-150 feet	43	14.0	327.5	363.7	36.2	1,310.44	4.00
151-200 feet	38	12.3	287.7	214.8	-72.9	5,314.41	18.47
201+ feet	63	20.4	477.2	354.3	-122.9	15,104.41	31.65
Total	308	100.0	2,339.3	2,339.3	0		74.69 = X^2 **
Second period--							
0- 50 feet	68	22.1	437.2	503.8	66.6	4,435.56	10.14
51-100 feet	96	31.2	617.2	639.8	22.6	510.76	.83
101-150 feet	43	14.0	277.0	327.5	50.5	2,550.25	9.21
151-200 feet	38	12.3	243.3	289.1	45.8	2,097.64	8.62
201+ feet	63	20.4	403.6	218.1	-185.5	34,410.25	85.26
Total	308	100.0	1,978.3	1,978.3	0		114.06 = X^2 **
TO CLOSEST UNIT:							
First period--							
0- 50 feet	28	10.9	160.8	146.3	-14.5	210.25	1.31
51-100 feet	107	41.6	613.9	594.4	-19.5	380.25	.62
101-150 feet	68	26.5	391.1	385.9	- 5.2	27.04	.07
151-200+ feet	54	21.0	309.9	349.1	39.2	1,536.64	4.96
Total	257	100.0	1,475.7	1,475.7	0		6.96 = X^2 *
Second period--							
0- 50 feet	28	10.9	261.3	132.6	-128.7	16,563.69	63.39
51-100 feet	107	41.6	997.2	982.2	-15.0	225.00	.22
101-150 feet	68	26.5	635.3	655.6	20.3	412.09	.65
151-200+ feet	54	21.0	503.4	626.8	123.4	15,227.56	30.25
Total	257	100.0	2,397.2	2,397.2	0		94.81 = X^2 **
TO FISHING POINT:							
First period--							
0- 50 feet	48	16.2	368.5	330.1	-38.4	1,474.56	4.00
51-100 feet	28	9.4	213.8	278.7	64.9	4,212.01	19.70
101-150 feet	24	8.1	184.3	207.5	23.2	538.24	2.92
151-200 feet	22	7.4	168.4	223.5	55.1	3,036.01	18.03
201+ feet	175	58.9	1,339.9	1,235.1	-104.8	10,983.04	8.20
Total	297	100.0	2,274.9	2,274.9	0		52.85 = X^2 **
Second period--							
0- 50 feet	48	16.2	281.6	336.1	54.5	2,970.25	10.55
51-100 feet	28	9.4	163.5	116.2	-47.3	2,237.29	13.68
101-150 feet	24	8.1	140.8	162.1	21.3	453.69	3.22
151-200 feet	22	7.4	128.6	127.8	-.8	6.4	.05
201+ feet	175	58.9	1,023.9	996.2	-27.7	767.29	.75
Total	297	100.0	1,738.4	1,738.4	0		28.25 = X^2 **
CLEARING RADIUS:[1]							
First period--							
0- 5 feet	65	15.9	462.9	469.8	6.9	47.61	0.10
6-10 feet	81	19.8	576.5	623.9	47.4	2,246.76	3.90
11-15 feet	98	24.0	698.8	662.8	-36.0	1,296.0	1.85
16-20 feet	84	20.5	596.9	472.6	-124.3	15,450.49	25.88
21-25 feet	42	10.3	299.9	340.5	40.6	1,648.36	5.50
26-30+ feet	39	9.5	276.6	342.0	65.4	4,277.16	15.46
Total	409	100.0	2,911.6	2,911.6	0		52.69 = X^2 **
Second period--							
0- 5 feet	65	15.9	484.5	269.7	-214.8	46,139.04	95.23
6-10 feet	81	19.8	603.4	334.1	-269.3	72,522.49	120.19
11-15 feet	98	24.0	731.3	773.8	42.5	1,806.25	2.47
16-20 feet	84	20.5	624.6	764.4	139.8	19,544.04	31.29
21-25 feet	42	10.3	313.8	492.6	178.8	31,969.44	101.88
26-30+ feet	39	9.5	289.5	412.5	123.0	15,129.0	52.26
Total	409	100.0	3,047.1	3,047.1	0		403.32 = X^2 **

** Significant at 1 percent.
* Significant at 6 percent.

[1] Based on maximum distance from fire grate to edge of disturbed area created by trampling or other activities that tended to destroy the ground cover.

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April 1964

U. S. Forest Service Research Paper RM-6

Volume Tables and Point-Sampling Factors

for

Lodgepole Pine in Colorado and Wyoming

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VOLUME TABLES AND POINT-SAMPLING FACTORS FOR LODGEPOLE PINE IN COLORADO AND WYOMING

by

Clifford A. Myers, Research Forester

Rocky Mountain Forest and Range Experiment Station[1]

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[1] Central headquarters maintained in cooperation with Colorado State University at Fort Collins.

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Volume Tables and Point-Sampling Factors

for Lodgepole Pine

in Colorado and Wyoming

by

Clifford A. Myers

INTRODUCTION

The tables presented here give values needed to determine the volumes of lodgepole pines (Pinus contorta Dougl.) in Colorado and Wyoming. They provide timber cruisers and growth estimators with the following:

1. Gross volumes in total and merchantable cubic feet,
2. Gross volumes in board feet, International 1/4-inch and Scribner log rules,
3. Point-sampling factors for merchantable cubic feet and board feet, and
4. Distribution of board-foot volume among the logs of a tree.

Volume on an area may be determined from:

1. Measurements of tree diameters and heights,
2. Measurements of diameters and of sufficient heights to convert the appropriate volume tables to local volume tables (Chapman and Meyer, 1949),[2] or
3. Tree counts obtained by point-sampling.

Sample trees were measured in all major areas of commercial lodgepole pine in Colorado and Wyoming.

DEFINITIONS AND STANDARDS

Definitions of variables used in the tables, and of standards followed in field measurement and computations, are as follows:

Diameter breast high (d.b.h.).--Measured to 0.1 inch outside bark 4.5 feet above average ground level. In the tables, full-inch diameter classes, with class midpoints at the half-inch marks, were used (12.5, 13.5, etc.).

Scaling diameter of logs.--Average diameter inside bark to 0.1 inch, measured at the upper (small) end of logs or half-logs. Saw-log diameter classes followed conventional scaling practice, with the class midpoints at whole inches (8.0, 9.0, etc.).

Minimum top diameter of sawtimber trees.--Diameter inside bark, 8 inches. Logs with a scaling diameter less than 7.6 inches (8-inch class) usually were not included in saw-log volume. A few logs with a scaling diameter of 7 inches were included to satisfy requirements of the 4-foot rule described with the definition of height in logs, below. This also conforms to local practice.

---

[2] *Names and dates in parentheses refer to Literature Cited, p. 4.*

Total height.--Measured to the nearest foot from average ground level at the tree base upward to the tip. Forked, stag-topped, or other deformed trees were not included in the sample. Midpoints of the total height classes used in the tables were multiples of 10.0 feet, as 10.0, 20.0, etc.

Height in logs.--Measured from the top of a stump 1.0 foot high upward to the limit of saw-log utilization. Each tree was divided into as many standard 16.3-foot-long logs as possible. An additional half-log, if present, was taken from the uppermost part of the merchantable length. Portions of the bole above the height of minimum top saw-log diameter were included in the uppermost saw log if the standard length of the log or half-log ended within 4.0 feet above this height. This "4-foot rule" was used to avoid biased negative error in volume (Chapman and Meyer, 1949).

EXPLANATION OF TABLES

The general definitions and standards given apply to all tables. Explanation of each type of table and suggestions for use are presented here.

Volume Tables

Headings and footnotes with each volume table (tables 1, 2, 4, 6, 8, 10) give the volume unit, type of height measurement, utilization standards, and volume equations used in its compilation. Ten-foot or half-log height classes and full-inch diameter classes were used in all tables.

The volume tables were derived from linear regressions in V and $D^2 H$, of the form:

$$V = a + b\,D^2 H$$

where

V = gross volume in the appropriate unit

D = diameter breast high outside bark

H = total height in feet or in standard logs and half-logs

a,b = regression constants

Two equations were used to derive each table; the relationship between V and $D^2 H$ could not be expressed by a single linear regression over the full range of the basic data. Correlation coefficients (r) of the 12 volume equations ranged from 0.908 (board feet with total height) to 0.990 (total cubic feet).

The number of logs in a tree shown in the tables is not necessarily the number that will actually be cut from it. Instead, it is the number of logs between the stump and the height where minimum top diameter is reached. To locate the minimum top, the 4-foot rule previously explained under "Height in logs" should be used.

Volume of nonmerchantable logs below the height of minimum top diameter should be deducted by estimation of scaling diameters, use of taper tables, or according to the percentages in table 13. Volume must not be reduced by tallying fewer logs in the tree. For example, assume that a sound tree 18 inches in diameter has a bole length of 65.2 feet (4 logs) between the stump and the height where diameter inside bark is 8 inches. The tree has a gross volume of 364 board feet Scribner rule (table 6). The top log is too limby to send to the sawmill. This log contains 8 percent of the board feet in the tree (table 13) and the other logs contain 92 percent. When 8 percent or 29 board feet is deducted, the tree contains 335 board feet. If the tree were tallied as an 18-inch, 3-log tree, it would be incorrectly credited with a volume of 275 board feet. Alternatively, the top log has a scaling diameter of 8 inches, thus 32 board feet (Scribner log rule) could be deducted from the volume of an 18-inch, 4-log tree.

POINT-SAMPLING FACTORS

The first five tables of point-sampling factors (tables 3, 5, 7, 9, 11) give the factors for each of numerous combinations of tree diameter and height. Volumes per square foot of basal area were obtained from the equations in the table footnotes. These equations resulted from the division of each volume equation (tables 2, 4, 6, 8, 10) by $0.005454\,D^2$, a formula for basal area (B).

Table 12 was derived from the other tables of point-sampling factors. The factor for each height class is the weighted average of the factors in that class given in table 2, 4, 6, 8, or 10. Weights were obtained from random samples of heights and diameters in stands of commercial lodgepole pine in Colorado and Wyoming.

Point-sample cruising for volume can be done in several ways:

1. Diameters and heights of trees counted through the prism or relascope may be measured,
2. Diameters may be estimated and heights measured, or
3. Heights of the counted trees may be measured and no record made of tree diameters.

The procedure selected will depend on the accuracy desired (relative accuracy usually in the order listed above) and the time and personnel available for the job. Point-sampling factors are provided for each alternative.

The diameter and height of each counted tree may be measured and a volume conversion factor selected for each combination of diameter and height (tables 3, 5, 7, 9, 11). Volume per acre is computed as follows:

1. Multiply the number of counted trees in each diameter-height class by the point-sampling factor for the class.
2. Total the products of step one.
3. Multiply this total by the basal area factor of the prism or other angle gage used.
4. Divide the product of step three by the number of points sampled on the tract.

Time can often be saved if the heights of the counted trees are measured while diameters are estimated and tallied by broad diameter classes. Inspection of the tables shows that volumes per square foot of basal area often do not differ greatly among trees of a single height class. For example, the merchantable volumes of trees 70 feet tall vary from 29.6 to 33.8 cubic feet per square foot over a range in diameter of 5 to 24 inches (table 3). Board feet per square foot of basal area changes little with diameter when tree heights are measured in logs (tables 7, 11). Therefore, the increased time spent measuring diameters may not result in any material increase in accuracy.

Measurement of heights with no record made of diameters is recommended when there is little change in volumes per square foot within a height class. Point-sampling factors in table 12, based on height only, will be most useful where the distributions of diameters within height classes approximate those used in preparation of the tables. Differences in the relationship between height and diameter due to differences in site quality or stand density may change the factor for each height class. These changes may be accounted for by computing new factors for each height class, using table 3, 5, 7, 9, or 11 and almost the same procedure used to derive a local volume table from a standard table (Chapman and Meyer, 1949). Diameters are plotted over heights since height will be retained as the measured variable.

The techniques of point sampling have been described in numerous publications. A good discussion of the method was presented by Bonnett (1959). A simple procedure for determination of the number of sampling points (Allen and Mogren, 1960) and precautions on the use of point-sampling on small tracts (Afanasiev, 1958) have been published. Basic American references were prepared by Grosenbaugh (1952, 1955, 1958).

Percentage of Tree Board-Foot Volume in Each Log

The board-foot volume in each log-quality class or the volume in cull logs can be determined with the percentages from table 13. Each line in the body of the table gives the distribution of volume among the logs of a tree of specified diameter and merchantable length. For example, in 18-inch, 3-log trees, the butt log contains 55 percent of the board feet, the middle log contains 33 percent, and the top log 12 percent.

Percentages for diameters that are not included in table 13 can be obtained by interpolation.

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Table 1.--Volumes of entire stem in cubic feet, lodgepole pines in Colorado and Wyoming

Cubic feet inside bark
Entire stem including stump and top

Total height above ground

Diameter breast height outside bark (inches)	Total height in feet								Basis: Trees
	30	40	50	60	70	80	90	100	
	Cubic feet								
2	0.55	0.72							0
3	1.05	1.39	1.73						6
4	1.71	2.28	2.84	3.40					22
5	2.55	3.39	4.23	5.07	5.91				33
6	3.55	4.72	5.89	7.07	8.24				25
7	4.71	6.28	7.84	9.40	11.0				34
8	6.05	8.05	10.1	12.1	14.1	16.1			45
9	7.55	10.1	12.6	15.1	17.6	20.3			59
10	9.21	12.3	15.3	18.4	21.4	24.0	26.6		101
11	11.0	14.7	18.4	22.0	25.0	28.1	31.2	34.3	93
12		17.4	21.7	25.3	29.0	32.6	36.2	39.9	69
13		20.4	24.7	28.9	33.2	37.4	41.7	45.9	32
14		23.1	28.0	32.9	37.8	42.7	47.6	52.5	20
15		25.9	31.5	37.1	42.7	48.3	53.9	59.5	9
16			35.2	41.5	47.9	54.2	60.6	66.9	20
17			39.2	46.3	53.4	60.6	67.7	74.9	11
18				51.3	59.3	67.3	75.3	83.3	12
19				56.7	65.5	74.4	83.3	92.1	2
20				62.2	72.0	81.8	91.6	101	1
21				68.1	78.9	89.7	100	111	2
22				74.3	86.1	97.9	110	122	5
23				80.7	93.6	106	119	132	4
24					101	115	129	143	1
25						125	140	155	0
Basis: No. trees	14	64	136	176	126	73	15	2	606

Block indicates extent of basic data.

Derived from $V = 0.002777\ D^2H + 0.027967$, for D^2H to 7,000.
$V = 0.002332\ D^2H + 3.446454$, for D^2H larger than 7,000.

Standard errors of estimate: ± 7.70 percent; ± 8.17 percent.

Diameter classes full inch; e.g., 20-inch class includes 20.0 to 20.9.

Table 2. --Merchantable volumes in cubic feet to a 4.0-inch top, lodgepole pines in Colorado and Wyoming

Cubic feet inside bark
Merchantable stem excluding stump and top

Top diameter 4.0 inches inside bark
Stump height 1.0 foot

Diameter breast height outside bark (inches)	Total height in feet								Basis: Trees
	30	40	50	60	70	80	90	100	
	- - - - - - - -	- - - - - - - -	- - - - - - - -	- - - - - - - -	Cubic feet	- - - - - - - -	- - - - - - - -	- - - - - - - -	
5	1.49	2.34	3.19	4.03	4.88				33
6	2.50	3.68	4.86	6.05	7.23				25
7	3.68	5.25	6.82	8.40	9.97				34
8	5.02	7.04	9.06	11.1	13.1	15.1			45
9	6.53	9.06	11.6	14.1	16.6	19.1			59
10	8.21	11.3	14.4	17.5	20.2	22.7	25.2		101
11	10.1	13.8	17.5	20.7	23.7	26.7	29.7	32.7	93
12		16.4	20.5	24.0	27.5	31.0	34.6	38.1	69
13		19.3	23.4	27.5	31.6	35.7	39.8	44.0	32
14		21.8	26.6	31.3	36.0	40.8	45.5	50.3	20
15		24.5	29.9	35.4	40.8	46.2	51.6	57.0	9
16			33.5	39.7	45.8	52.0	58.1	64.3	20
17			37.4	44.3	51.2	58.1	65.0	71.9	11
18			41.4	49.2	56.9	64.6	72.3	80.0	12
19			45.7	54.3	62.9	71.5	80.0	88.6	2
20				59.7	69.2	78.7	88.2	97.6	1
21				65.4	75.8	86.3	96.7	107	2
22				71.4	82.8	94.2	106	117	5
23				77.6	90.0	103	115	127	4
24					97.6	111	125	138	1
25						120	135	150	0
Basis: No. trees	4	47	135	176	126	73	15	2	578

Block indicates extent of basic data.

Derived from $V = 0.002798 D^2 H - 1.045780$, for $D^2 H$ to 7,000.
$V = 0.002256 D^2 H + 2.836222$, for $D^2 H$ larger than 7,000.

Standard errors of estimate: ± 9.28 percent; ± 8.77 percent.

Diameter classes full inch; e.g., 20-inch class includes 20.0 to 20.9.

Table 3.--Merchantable volumes in cubic feet per square foot of basal area, lodgepole pines in Colorado and Wyoming

Cubic feet inside bark
Merchantable stem excluding stump and top

Top diameter 4.0 inches inside bark
Stump height 1.0 foot

Diameter breast height outside bark (inches)	Total height in feet							
	30	40	50	60	70	80	90	100
	Cubic feet							
5	9.1	14.2	19.3	24.4	29.6			
6	10.9	16.0	21.1	26.2	31.4			
7	12.0	17.1	22.2	27.4	32.5			
8	12.7	17.9	23.0	28.1	33.3	38.4		
9	13.3	18.4	23.5	28.7	33.8	38.8		
10	13.7	18.8	23.9	29.0	33.7	37.8	41.9	
11	13.9	19.1	24.2	28.7	32.9	37.0	41.2	45.3
12		19.3	24.0	28.1	32.3	36.4	40.6	44.7
13		19.4	23.5	27.7	31.8	35.9	40.1	44.2
14		19.0	23.2	27.3	31.4	35.6	39.7	43.8
15		18.7	22.8	27.0	31.1	35.3	39.4	43.5
16			22.6	26.7	30.9	35.0	39.1	43.3
17			22.4	26.5	30.6	34.8	38.9	43.1
18			22.2	26.3	30.5	34.6	38.7	42.9
19			22.0	26.2	30.3	34.5	38.6	42.7
20				26.1	30.2	34.3	38.5	42.6
21				25.9	30.1	34.2	38.3	42.5
22				25.8	30.0	34.1	38.3	42.4
23				25.8	29.9	34.0	38.2	42.3
24					29.8	34.0	38.1	42.2
25						33.9	38.0	42.2

Derived from: $V/B = 0.5130H - 191.7455/D^2$, above dotted line.

$V/B = 0.4136H + 520.0260/D^2$, below dotted line.

Diameter classes full inch; e.g., 20-inch class includes 20.0 to 20.9.

Table 4.--Volumes in board feet Scribner Rule, lodgepole pines in Colorado and Wyoming

Board feet inside bark
Merchantable stem excluding stump and top

Top diameter 8 inches inside bark
Stump height 1.0 foot

Diameter breast height outside bark (inches)	Total height in feet								Basis: Trees
	40	50	60	70	80	90	100	110	
	Board feet								
10	35	49	63	77	90	104			122
11	46	63	79	96	112	129			109
12	58	78	97	117	136	156			96
13	71	94	117	140	163	182	206		52
14	85	112	138	164	188	215	242	269	39
15	100	130	161	188	219	250	281	311	27
16	116	150	181	216	252	287	322	357	36
17	133	168	208	247	287	326	366	405	19
18	151	191	236	280	324	368	412	456	20
19	167	216	265	314	363	412	461	510	8
20		242	296	350	404	458	513	567	4
21		269	328	388	448	507	567	626	5
22			362	428	493	558	623	689	5
23			398	469	540	612	683	754	4
24				512	590	667	745	822	1
25					641	725	809	893	2
Basis: No. trees	8	76	186	156	90	30	3	0	549

Block indicates extent of basic data.

Derived from $V = 0.012535\ D^2H - 20.190570$, for D^2H to 15,000.
$V = 0.012893\ D^2H - 29.245660$, for D^2H larger than 15,000.

Standard errors of estimate: $\pm$ 17.35 percent; $\pm$ 14.60 percent.

Diameter classes full inch; e.g., 20-inch class includes 20.0 to 20.9.

Table 5.--Volumes in board feet Scribner Rule per square foot of basal area, lodgepole pines in Colorado and Wyoming

Board feet inside bark
Merchantable stem excluding stump and top

Top diameter 8 inches inside bark
Stump height 1.0 foot

Diameter breast height outside bark (inches)	Total height in feet							
	40	50	60	70	80	90	100	110
	Board feet							
10	58	81	104	127	150	173		
11	64	87	110	133	156	179		
12	68	91	114	137	160	183		
13	72	95	118	141	164	183	207	
14	74	97	120	143	164	187	211	235
15	77	100	122	143	167	190	214	238
16	78	101	122	146	169	193	217	240
17	80	101	124	148	172	195	219	243
18	81	103	126	150	173	197	221	244
19	80	104	128	151	175	199	222	246
20		105	129	153	176	200	224	247
21		107	130	154	178	201	225	248
22			131	155	179	202	226	249
23			132	156	179	203	227	250
24				157	180	204	227	251
25					181	205	228	252

Derived from: $V/B = 2.2983H - 3701.9747/D^2$, above dotted line.

$V/B = 2.3640H - 5362.2406/D^2$, below dotted line.

Diameter classes full inch; e.g., 20-inch class includes 20.0 to 20.9.

Table 6. --Volumes in board feet Scribner Rule, lodgepole pines in Colorado and Wyoming

Board feet inside bark
Merchantable stem excluding stump and top

Top diameter 8 inches inside bark
Stump height 1.0 foot

Diameter breast height outside bark (inches)	Number of 16-foot logs to 8-inch top									Basis: Trees
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	
	Board feet									
10	42	56	70	84	98					122
11	47	64	81	98	115	132	149			109
12	53	73	93	113	133	153	173			96
13	60	83	107	130	153	176	200			52
14		94	121	148	174	201	228	255		39
15		106	136	167	197	228	259	289		27
16		118	152	187	222	257	291	326	362	36
17		131	170	209	248	287	326	366	406	19
18			188	232	275	319	364	409	453	20
19			208	256	304	354	404	453	503	8
20			228	282	335	390	445	500	556	4
21			249	308	368	429	489	550	611	5
22				337	403	469	536	602	668	5
23					439	511	584	656	728	4
24						555	634	713	791	1
25						601	686	772	857	2
Basis: No. trees	9	75	155	150	82	46	28	3	1	549

Block indicates extent of basic data.

Derived from $V = 0.255015\ D^2H + 13.620940$, for D^2H to 1,100.
$V = 0.261983\ D^2H + 5.030200$, for D^2H larger than 1,100.

Standard errors of estimate: ± 13.28 percent, ± 10.69 percent.

Diameter classes full inch; e.g. 20-inch class includes 20.0 to 20.9.

Table 7. --Volumes in board feet Scribner Rule per square foot of basal area, lodgepole pines in Colorado and Wyoming

Board feet inside bark
Merchantable stem excluding stump and top

Top diameter 8 inches inside bark
Stump height 1.0 foot

Diameter breast height outside bark (inches)	Number of 16-foot logs to 8-inch top								
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
	Board feet								
10	69	93	116	140	163				
11	66	89	112	136	159	183	206		
12	63	86	109	133	156	180	203		
13	60	84	107	131	154	177	201		
14		82	105	129	152	176	199	222	
15		81	104	127	151	174	197	221	
16		79	103	126	149	173	196	220	244
17		78	102	125	148	172	195	219	243
18			101	124	148	171	195	219	243
19			100	123	147	171	195	219	243
20			99	123	146	170	194	218	242
21			99	122	146	170	194	218	242
22				122	146	170	194	218	242
23					146	170	194	218	242
24						170	194	218	242
25						170	194	218	242

Derived from $V/B = 46.7574\,H + 2497.4221/D^2$, above dotted line.
$V/B = 48.0350\,H + 922.2956/D^2$, below dotted line.

Diameter classes full inch;e.g., 20-inch class includes 20.0 to 20.9.

Table 8.--Volumes in board feet International 1/4 inch Rule, lodgepole pines in Colorado and Wyoming

Board feet inside bark
Merchantable stem excluding stump and top

Top diameter 8 inches inside bark
Stump height 1.0 foot

Diameter breast height outside bark (inches)	Total height in feet								Basis: Trees
	40	50	60	70	80	90	100	110	
	- - - - - - - - - - - - - - - - - -				Board feet - - - - - - - - - - - - - - - -				
10	40	57	74	90	107	124			122
11	54	74	94	113	133	153			109
12	68	92	115	139	162	186			96
13	84	111	139	166	194	219	245		52
14	101	132	164	196	225	254	283	312	39
15	119	155	191	225	258	291	324	357	27
16	138	179	219	256	294	331	368	406	36
17	159	204	247	289	331	373	415	457	19
18	180	229	276	323	371	418	465	512	20
19	203	255	308	360	412	465	517	569	8
20		283	341	399	457	514	572	630	4
21		312	375	439	503	566	630	694	5
22			412	482	551	621	691	760	5
23			450	526	602	678	754	830	4
24				572	655	737	820	903	1
25					710	799	889	978	2
Basis: No. trees	8	76	186	156	90	30	3	0	549

Block indicates extent of basic data.

Derived from $V = 0.015097\ D^2H - 26.287820$, for D^2H to 15,000.
$V = 0.013766\ D^2H - 6.309990$, for D^2H larger than 15,000.

Standard errors of estimate: $\pm$ 17.53 percent; $\pm$ 14.34 percent.

Diameter classes full inch; e.g., 20-inch class includes 20.0 to 20.9.

Table 9.--Volumes in board feet International 1/4-inch Rule per square foot of basal area, lodgepole pines in Colorado and Wyoming

Board feet inside bark
Merchantable stem excluding stump and top

Top diameter 8 inches inside bark
Stump height 1.0 foot

Diameter breast height outside bark (inches)	Total height in feet							
	40	50	60	70	80	90	100	110
	Board feet							
10	67	95	122	150	178	205		
11	74	102	130	157	185	213		
12	80	108	135	163	191	218		
13	84	112	140	167	195	221	246	
14	88	115	143	171	196	222	247	272
15	91	118	146	172	197	222	248	273
16	93	121	147	172	198	223	248	273
17	95	122	148	173	198	223	249	274
18	97	123	148	173	199	224	249	274
19	98	123	148	174	199	224	249	275
20		123	149	174	199	224	250	275
21		124	149	174	199	225	250	275
22			149	174	200	225	250	275
23			149	175	200	225	250	276
24				175	200	225	250	276
25					200	225	251	276

Derived from: $V/B = 2.7681H - 4819.9157/D^2$, above dotted line.

$V/B = 2.5240H - 1156.9472/D^2$, below dotted line.

Diameter classes full inch; e.g., 20-inch class includes 20.0 to 20.9.

Table 10. --Volumes in board feet International 1/4-inch Rule, lodgepole pines in Colorado and Wyoming

Board feet inside bark
Merchantable stem excluding stump and top

Top diameter 8 inches inside bark
Stump height 1.0 foot

Diameter breast height outside bark (inches)	Number of 16-foot logs to 8-inch top									Basis: Trees
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	
	Board feet									
10	49	66	82	99	116					122
11	56	76	96	116	136	156	175			109
12	63	87	110	134	157	181	204			96
13	71	98	126	153	181	208	236			52
14		111	143	174	206	238	269	301		39
15		125	161	197	233	269	306	338		27
16		139	180	221	262	303	340	377	414	36
17		154	201	247	293	336	377	419	460	19
18			222	274	324	370	416	463	509	20
19			245	302	354	406	457	509	560	8
20			269	330	387	444	501	558	614	4
21			295	358	421	484	546	609	671	5
22				388	457	525	594	662	731	5
23					494	569	644	718	793	4
24						614	696	777	858	1
25						662	750	838	926	2
Basis: No. trees	9	75	155	150	82	46	28	3	1	549

Block indicates extent of basic data.

Derived from $V = 0.301244\ D^2H + 16.069730$, for D^2H to 1,000.
$V = 0.270735\ D^2H + 45.578690$, for D^2H larger than 1,000.

Standard errors of estimate: ± 13.50 percent; ± 10.23 percent.

Diameter classes full inch; e.g., 20-inch class includes 20.0 to 20.9.

Table 11. --Volumes in board feet International 1/4-inch Rule per square foot of basal area, lodgepole pines in Colorado and Wyoming

Board feet inside bark
Merchantable stem excluding stump and top

Top diameter 8 inches inside bark
Stump height 1.0 foot

Diameter breast height outside bark (inches)	Number of 16-foot logs to 8-inch top								
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
	Board feet								
10	82	110	137	165	192				
11	78	105	133	160	188	216	243		
12	74	102	129	157	185	212	240		
13	71	99	127	154	182	209	237		
14		97	124	152	180	207	235	263	
15		95	123	150	178	206	233	258	
16		94	121	149	177	204	229	254	279
17		92	120	148	175	201	226	251	275
18			119	147	173	198	223	248	273
19			118	146	171	196	221	245	270
20			117	144	169	194	218	243	268
21			117	142	167	192	217	241	266
22				141	165	190	215	240	265
23					164	189	214	239	263
24						188	212	237	262
25						187	211	236	261

Derived from $V/B = 55.2336\ H + 2946.4118/D^2$, above dotted line.

$V/B = 49.6397\ H + 8356.9289/D^2$, below dotted line.

Diameter classes full inch; e.g., 20-inch class includes 20.0 to 20.9.

Table 12. --Tree volumes per square foot of basal area by tree height classes only, lodgepole pines in Colorado and Wyoming

Tree height (feet)	Merchantable cubic feet	Board feet		Tree height (logs)	Board feet	
		Scribner	International		Scribner	International
30	10.3	--	--	1.0	68	80
40	15.9	67	78	1.5	91	108
50	22.9	87	103	2.0	112	132
60	28.3	113	134	2.5	133	156
				3.0	153	179
70	32.5	138	163	3.5	174	203
80	36.1	163	192	4.0	196	226
90	39.8	190	221	4.5	219	250
100	43.5	219	250	5.0	242	275

Table 13. --Percentage of total board-foot volume in each log of a tree, lodgepole pines in Colorado and Wyoming

Diameter breast height outside bark (inches) and tree height (logs)	Position of log in the tree								
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
	Percent of total tree volume								
Trees 10 inches d.b.h.:									
1.0	100								
1.5	72	28							
2.0	58	--	42						
2.5	48	--	36	16					
3.0	41	--	31	--	28				
3.5	36	--	27	--	25	12			
Trees 14 inches d.b.h.:									
1.5	76	24							
2.0	65	--	35						
2.5	55	--	34	11					
3.0	47	--	33	--	20				
3.5	41	--	31	--	21	7			
4.0	37	--	30	--	22	--	11		
Trees 18 inches d.b.h.:									
2.0	75	--	25						
2.5	64	--	29	7					
3.0	55	--	33	--	12				
3.5	47	--	32	--	16	5			
4.0	42	--	29	--	21	--	8		
4.5	38	--	25	--	25	--	8	4	
Trees 22 inches d.b.h.:									
2.5	75	--	20	5					
3.0	61	--	28	--	11				
3.5	50	--	32	--	14	4			
4.0	45	--	29	--	20	--	6		
4.5	41	--	26	--	21	--	9	3	
5.0	38	--	25	--	22	--	12	--	3

Myers, Clifford A.
1964. Volume tables and point-sampling factors for lodgepole pine in Colorado and Wyoming. U. S. Forest Serv. Res. Paper RM-6, 16 pp. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Volumes are in total cubic feet and cubic feet to a 4.0-inch top, board feet Scribner Rule to an 8-inch top, and board feet International 1/4-inch Rule to an 8-inch top. Tree heights are in feet and numbers of logs. Volume equations are of the form $V = a + bD^2H$.

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1964. Volume tables and point-sampling factors for lodgepole pine in Colorado and Wyoming. U. S. Forest Serv. Res. Paper RM-6, 16 pp. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

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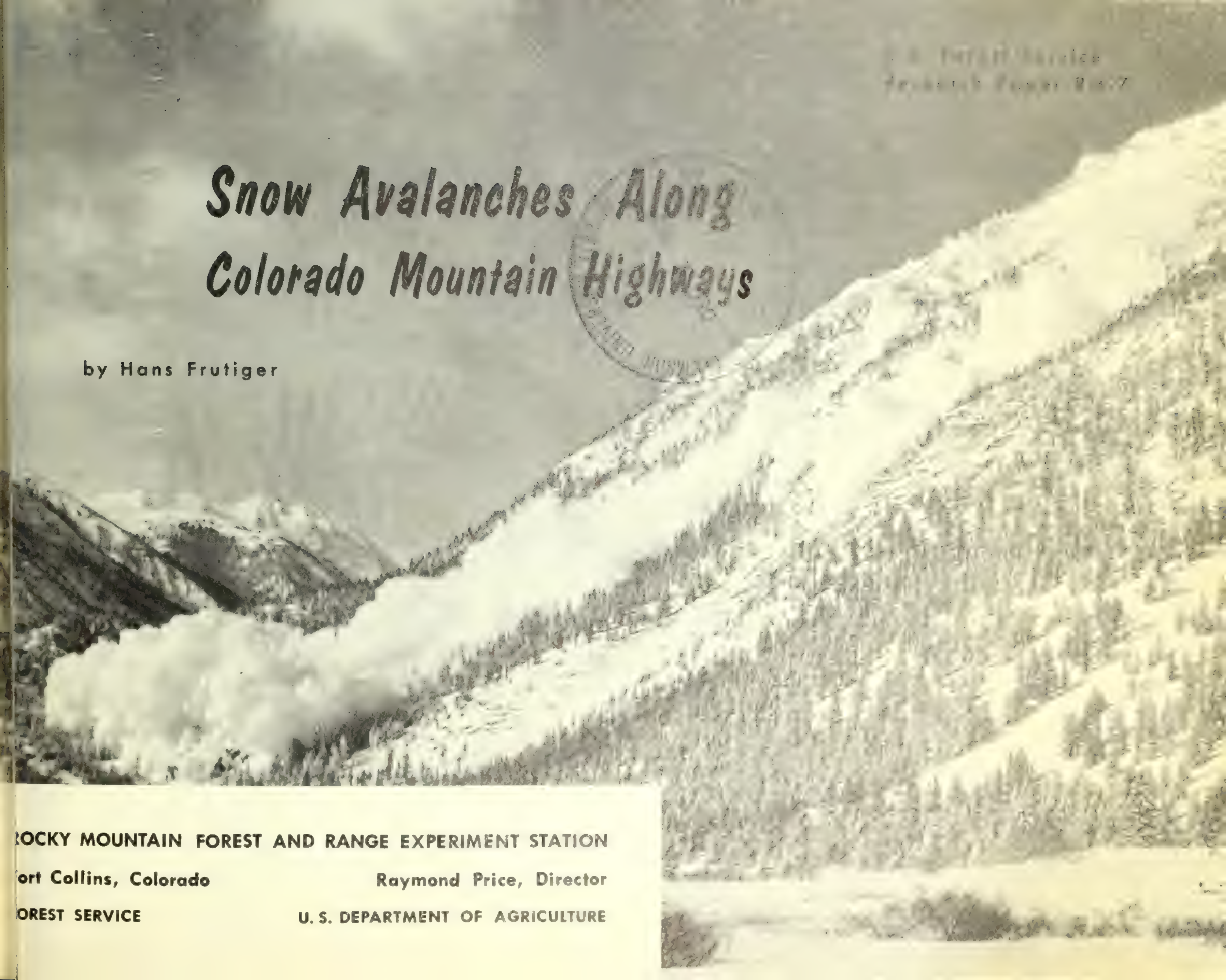

U.S. Forest Service
Research Paper RM-7

Snow Avalanches Along Colorado Mountain Highways

by Hans Frutiger

ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Fort Collins, Colorado Raymond Price, Director
FOREST SERVICE U. S. DEPARTMENT OF AGRICULTURE

U. S. Forest Service Research Paper RM-7 July 1964

SNOW AVALANCHES
ALONG COLORADO MOUNTAIN HIGHWAYS

by

Hans Frutiger[1]

Rocky Mountain Forest and Range Experiment Station[2]

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[1] Forest Engineer, Swiss National Institute for Snow and Avalanche Research, Davos, Switzerland. The author, on leave of absence, was employed by Colorado State University for this cooperative project with the Rocky Mountain Forest and Range Experiment Station.

[2] Central headquarters maintained in cooperation with Colorado State University at Fort Collins.

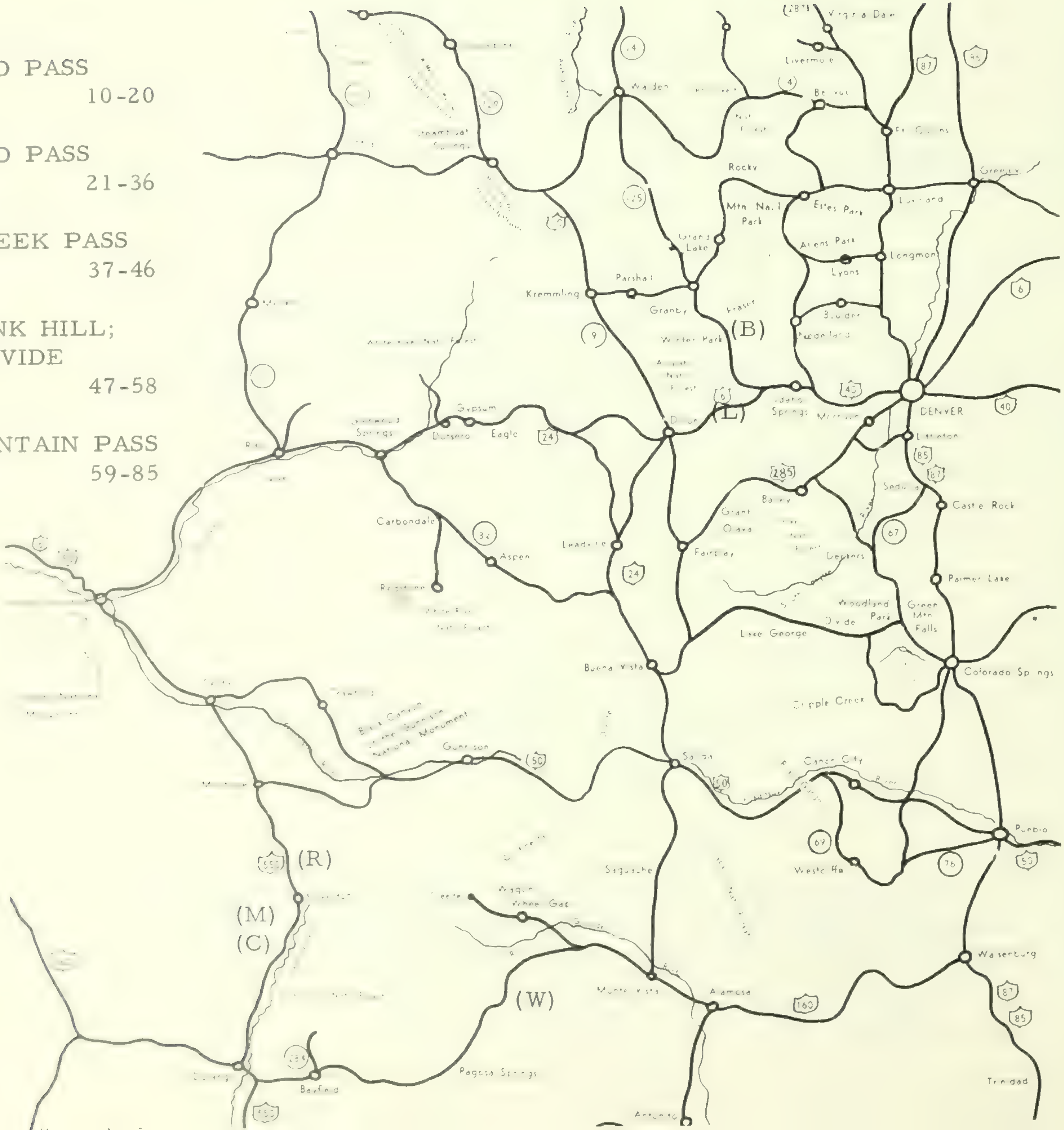
(B) BERTHOUD PASS 10-20

(L) LOVELAND PASS 21-36

(W) WOLF CREEK PASS 37-46

(C) COAL BANK HILL;
(M) MOLAS DIVIDE 47-58

(R) RED MOUNTAIN PASS 59-85



Snow Avalanches Along Colorado Mountain Highways

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Hans Frutiger

SCOPE OF THE REPORT

One of the first steps in any avalanche control program is to inventory and assess problem areas. Since a complete inventory of all the avalanches in Colorado is not feasible at this time, four mountain passes were chosen for study.[3] Two of the areas, Highways 40 across Berthoud Pass and 6 over Loveland Pass, are in the Front Range of central Colorado; the others, Highways 160 over Wolf Creek Pass and 550 over Red Mountain Pass, are in the San Juan Mountains of southwestern Colorado. These four areas form a representative sample of the avalanche problems in the Colorado mountains. A discussion of avalanche characteristics and control possibilities in the study area will give general information that should be helpful in planning avalanche control measures based on practices currently used in central Europe.

The intent of this report is twofold: (1) to give a generalized picture of avalanches in the mountains of Colorado, their number, frequency, size, general configuration, and structural control possibilities; and (2) to identify, locate, and illustrate the avalanches in the four areas chosen for study.

Structural control possibilities described here are based on current practices in central Europe. For our purposes, the following control possibilities will be considered:

1. Supporting structures in the starting zone: These are concrete and metal snow bridges (Schneebrücke), snow rakes (Schneerechen), and snow nets (Lawinennetze). Such structures prevent avalanches from starting because they literally support the snow cover in the starting zone.
2. Structural control in the track or runout zone: Retarding, deflecting, and catching structures intended to slow down, deflect, or stop avalanches in the runout zone or the lower part of the avalanche track. These are usually massive earthen mounds or dams. They are often armored on the uphill side with concrete or masonry.
3. Direct protection structures: These are primarily avalanche sheds. Such structures carry the avalanches over the road without interrupting traffic. Large earthen catchment dams near the road are also considered in this category.

Avalanches along Colorado highways are currently controlled by the use of explosives. Artillery shells fired into the starting zones either stabilize the snow in place or release avalanches at a time when highway crews are ready to clear the road. This system has proven effective in most cases,[4] and it is not certain whether structural controls would be better. Of course, each control system has its advantages and disadvantages. The use of explosives to control avalanches permits the use of existing crews and equipment at a low annual cost. Explosives are no protection to the roads during heavy storms, however, and the roads are often closed by slides. This technique also perpetuates and accentuates the avalanche paths. Structural control, on the other hand, may be very expensive initially, but well designed structural control gives protection for a number of years, and in many cases provides an opportunity to reestablish a forest--one of the best avalanche defenses known.

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[3] *Quadrangle maps of the U. S. Geological Survey have been used to show locations of the avalanches.*

[4] *Miles, George N. Snow removal. 9 pp. Paper presented by Colo. Dept. Highways, 47th Ann. Mtg., Amer. Assoc. State Highway Officials, Denver, Oct. 1961.*

When structural avalanche control is begun, the first efforts should be concentrated in areas where there is no question about the type of structure to use. After experience has been gained on how avalanche defense systems work in such places, the more difficult and questionable areas can be treated. As an illustration, the STANLEY avalanche near Berthoud Pass starts in a relatively small catchment basin. It spreads over a wide area and crosses the highway twice in its course down the mountain. There is not enough room for diversion or retarding structures above the road. To protect both limbs of the switchback, 2,000 to 3,000 feet of avalanche shed would be needed. On the other hand, supporting structures could be built in the starting zone since the catchment basin is well defined and easily accessible. In this case, stabilization of the starting zone would undoubtedly be the most economical procedure. Afforestation in the lower parts of the avalanche area would make defense work more efficient.

EAST RIVERSIDE avalanche on Red Mountain Pass, on the other hand, is a classic example of a situation where an avalanche shed or a tunnel is the obvious solution. The snow masses start in a big catchment basin and are well channelized in the narrow gully of Curran Gulch. About 1,000 feet of avalanche shed or tunnel would completely protect the highway from both the EAST RIVERSIDE and WEST RIVERSIDE avalanches (see map p. 62). The starting zone of these two avalanches totals 225 acres (90 hectares). All of this area lies at high altitudes and is accessible only with great difficulty.

Further discussion of the principles of structural avalanche control is given in two publications[5] [6] available from the Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Field data were gathered during the winter of 1961-62 and the following summer. Direct observations were facilitated and augmented by discussions with Colorado State Highway personnel. Comments in the description section of this report on snow conditions in the starting zones of the avalanches have been kept short. One winter's observations are not enough to permit very definite statements. Detailed winter observations will be needed in any area where structural controls are contemplated. Schaerer's[7] [8] [9] reports are good examples of the type of planning needed to integrate avalanche control measures into the construction and maintenance of a mountain highway.

Avalanche names used in this report are those used by the local people. Names were selected for the few avalanches that had none. In a few cases, avalanches shown on the sketch maps of the Highway Department could not be located in the field; these were omitted from this report.

The designation Red Mountain Pass as used here includes two sections of Highway 550 that are topographically separated from Red Mountain Pass proper. These are Coal Bank Hill from Cascade Creek to Lime Creek, and Molas Divide from Lime Creek to Silverton.

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[5] *Federal Inspection of Forests, Berne, Switzerland. Avalanche control in the starting zone: guidelines for the planning and design of permanent supporting structures. Translated by Hans Frutiger in Sta. Paper 71, 60 pp., illus. 1962.*

[6] *Frutiger, Hans. Planning structural control of avalanches. (Being reviewed for publication).*

[7] *Schaerer, P. Avalanche defences for the Trans-Canada highway at Rogers Pass. Canada Natl. Res. Coun. Div. Bldg. Res. Tech. Paper 141, 35 pp., illus.*

[8] *Schaerer, P. The avalanche hazard evaluation and prediction at Rogers Pass. Canada Natl. Res. Coun. Div. Bldg. Res. Tech. Paper 142, 32 pp., illus.*

[9] *Schaerer, P. Planning avalanche defence works for the Trans-Canada highway at Rogers Pass, B. C. Canada Natl. Res. Coun. Div. Bldg. Res. Res. Paper 152, 12 pp., illus.*

AN AVALANCHE CLASSIFICATION SYSTEM

In this section, avalanches are classified into a few types based on size, frequency, and terrain conditions, since these criteria are important for planning structural avalanche control.

Small avalanches that run after or during each snowstorm are more troublesome than large ones that run only at long intervals. On the other hand, after a large avalanche has run, it takes more effort to clear and reopen the highway. While frequency and size determine the seriousness of a given avalanche, terrain conditions determine the possibilities of structural control. A small avalanche can be as hazardous as a large one--it makes no difference to the people involved if they are suffocated in a big or a small snow mass. The cost of snow removal and especially of structural control is very much dependent upon size. It should be emphasized, however, that a small avalanche may be the indirect cause of a great disaster because traffic stopped by a small slide at an unsafe spot may be exposed to the hazard of other avalanches.

Size Classification

As used here, size refers to the extent of the starting zone and not to the amount of snow brought down by the avalanche. The general area of the starting zone is constant; the amount of snow that slides varies greatly with the actual avalanching conditions. Even in the starting zone, there are usually big patches that are safe and do not slide. Thus size, estimated from large-scale maps, is only a rough figure that indicates the order of magnitude rather than an accurate surface area. In all cases, the size given is probably the upper limit of the starting zone.

A rough estimate of the costs necessary to control an avalanche in its starting zone can be determined from the size of the avalanche. In Switzerland, experience has shown that it costs 1 million Swiss francs ($250,000) to control a catchment basin of 10 acres (4 ha).

Bankslides

Bankslides as defined here start in the immediate proximity of the highway and have a track less than 160 feet (50 meters) long. They occur rather frequently and cause a great deal of trouble for snow removal crews, but they are not very dangerous to traffic. The most effective countermeasures depend on the particular slide. Sometimes supporting structures like those proposed for the starting zone of avalanches could be used. Other situations might require better stabilization of the cut bank with walls, wire netting, and later planting to vegetation.

Small avalanches

Small avalanches--those with a starting zone of 7 acres (3 ha) or less--often lie below timberline. In almost all cases, control by supporting structures in the starting zone is possible and economical.

Medium avalanches

Avalanches with starting areas between 7 and 30 acres (3 and 12 ha) are classed as medium sized. In this size class, the nature of the terrain determines how easily the avalanche can be controlled by structures in the starting zone.

Large avalanches

Avalanches with more than 30 acres (12 ha) of starting area are classified as large. Only under the most favorable or special conditions should control in the starting zone be tried for this size avalanche. Good examples of this class are WEST RIVERSIDE and EAST GUADALUPE, both on Highway 550 and both with catchment basins of 150 acres (60 ha).

Frequency Classification

Hazard increases rapidly with density of traffic and frequency of avalanches. Therefore, the frequency of occurrence is a very important criterion for avalanche classification. In recent years, avalanche hazard on mountain highways has increased rapidly because of winter sports. Traffic is densest at the time avalanches are to be expected. The more cars underway during an avalanche cycle, the greater the probability that a car will be hit. It should be pointed out that it takes time to release and clean up an avalanche with explosives, and during this time traffic is stopped. Where traffic is light, this might be practical; with heavy traffic, however, this procedure becomes questionable.

The following frequency classification distinguishes between avalanches that in the words of the highway maintenance crews "give much trouble" and others that "give little trouble." The frequency classifications assigned to specific avalanches in the following sections may be subject to criticism and later revision since they are based on limited information.

Frequent avalanches

An avalanche is classified as frequent when it runs during or after each medium to large snowstorm; in other words, an avalanche that runs once to several times a winter is called frequent. Because they run so often, the track is usually clean and such avalanches normally bring no debris to the road. This means the highway can be reopened soon after the slide has run. Avalanches that are frequent and "give much trouble" are usually well known by the maintenance crews and, in most cases, by the general public.

Occasional avalanches

Avalanches that run to the highway once in every 3 to 6 years are called occasional. Such avalanches normally stop traffic for a longer time than the more frequent ones, since they usually bring down rocks, trees, and other debris that make cleaning the highway a slow job. This class of avalanche runs too frequently to be ignored, yet not frequently enough to justify a great expenditure for control. Terrain conditions will usually determine whether or not structural control is economically feasible.

Erratic avalanches

Avalanches that run to the highway no more often than once in 7 to 10 years are called erratic avalanches. The term "seldom" was intentionally avoided in describing the frequency of these avalanches, even though they may not run for decades. It is quite possible that severe avalanche conditions will develop in several succeeding winters. In this case, such avalanches may run several times in a short span of years. The frequency of intermittent avalanches can be estimated from the vegetation in their tracks. When such slides do run, they usually run big and often bring a mass of debris down to the road.

The terms "erratic," "occasional," and "frequent" refer to how often the avalanches come to the highway. The example of GRIZZLY on Highway 6 might illustrate the situation: GRIZZLY has a tremendous catchment basin; after each medium to large snowstorm, there are avalanches in its starting zone and the middle section of the track. But the track is too long, too curved, and not steep enough to allow these avalanches to run to the highway below. It takes exceptionally severe conditions to cause a large enough avalanche to cross the highway.

Terrain Classification

Terrain conditions are the decisive factors determining whether structural control, especially in the starting zone, is recommended.

Location of starting zone in relation to timberline

The most important terrain consideration is whether the starting zone is above or below timberline. This distinction has an important bearing on the efficiency of the structures and on their maintenance. Below timberline the help of afforestation cannot be emphasized enough, even though the current thinking in Colorado seems to be that young trees grow too slowly and are too expensive to justify extensive plantings. Structural control and forest cover are needed, however, to give full protection in many areas. There are a considerable number of avalanche areas where control is more a matter of afforestation than of civil engineering.

Also, there is a remarkable increase in wind action above timberline compared to the timbered area. Above timberline, snow depositions are much more irregular than below, and excessive snow depths in particular spots are common.

Steepness of terrain

The ruggedness of the catchment basin is another important criterion in terrain classification. Very steep spots, even quite small ones, are very difficult to control. The general practice in central Europe is to use supporting structures to control avalanches with slopes between 62 and 120 percent. The cost of structural control in very steep starting zones is almost prohibitive.

Types of avalanche tracks

For structural control purposes, it is important to distinguish between channeled avalanches and unconfined avalanches.

The catchment basin of the channeled avalanche is well defined, usually bowl shaped, and the avalanche follows a clearly defined track that is usually a gully or other obvious depression in the slope. In the case of an unconfined avalanche, it is difficult to determine the starting zone and to delineate the course the moving snow masses will follow. The snow spreads over a wide area. It is evident that more observations and care are needed to develop an adequate plan for the control of unconfined avalanches. On the other hand, this kind might be very economical to control if observations show relatively small starting spots compared with the width of the track. In such cases, a few structures might protect a long section of the highway.

A good example of the channeled type is WEST RIVERSIDE on Highway 550. Although the catchment basin is very large (150 acres or 60 ha), the starting spots can be located easily from the topography, and the avalanche always follows a well-defined track, carved forever in the hard rock.

Just the opposite feature is exemplified by SLIPPERY JIM on the west-facing slope about a thousand feet south and across the valley from WEST RIVERSIDE. There is no well-defined catchment basin for this avalanche. It seems that the snow may start to come down anywhere; however, scattered tree groups make it evident that the whole slope does not run, at least under normal conditions. The starting spots and the normal track are not obvious to the casual observer. Other examples of unconfined avalanches are FLORAL PARK on Highway 40, the BROOKLYNS on Highway 550, and IRONTON PARK on Highway 550.

Longitudinal profile of avalanche track

The longitudinal profile of the track is of great importance for structural control in the track. A steep, narrow track is not favorable for retarding or catchment structures. The longitudinal profile must show some flat section that is both long enough and wide enough to slow down the avalanche naturally. Retarding and catchment structures would be effective in such a flat section. On Highway 550, there are examples of both types of longitudinal profiles: EAST RIVERSIDE has a narrow track that hits the highway directly without a transition zone. The runout zone is absent. The track of EAST GUADALUPE, on the other hand, shows a long transition zone before it reaches the highway, where, under favorable conditions, the avalanche stops naturally and where retarding or catchment structures would be effective.

BRIEF ANALYSIS OF AVALANCHE AREAS

An analysis of the 80 avalanche areas described in this report permits some generalizations about the characteristics of avalanches in Colorado and their control possibilities (table 1, figs. 1-3).

The avalanches are distributed as follows:

Berthoud Pass, Highway 40	12
Loveland Pass, Highway 6	13
Wolf Creek Pass, Highway 160	12
Red Mountain Pass, Highway 550	43
Total	80

The size of the starting zone varies from 1 acre to 150 acres. Avalanches with 2 to 30 acres (1 to 12 ha) are most common; only about 16, or about a fifth, are larger. The starting zones generally lie at an altitude of about 10,000 to 12,000 feet m.s.l. (mean sea level). Very often the upper parts are near timberline, which is between 11,400 and 11,800 feet m.s.l. in the southern Rocky Mountains.

The length and steepness of the tracks vary considerably. It is logical that short to medium tracks usually have a steeper slope than very long ones. Nearly half the total avalanches (35), have a track between 1,000 and 3,000 feet with an average slope between 50 and 70 percent; slopes between 60 and 70 percent are most common. Only 12 tracks are shorter than 1,000 feet and 23 are longer than 3,000 feet. The longest track is 6,000 feet. The average slope on the longer tracks is between 50 and 60 percent.

Avalanches are grouped according to their significance to traffic and the possibilities of structural control (table 1, fig. 2). Group 1 consists of the small-frequent avalanches. These are very hazardous to traffic, and could be controlled with little effort. In almost all cases, supporting structures in the starting zones and afforestation are recommended.

Group 2 consists of the medium-frequent and medium-occasional avalanches. These cases give trouble to traffic as well as to the avalanche control engineer. They are too frequent to be neglected, but too large to be controlled easily. Special studies of the particular area and, more important, an evaluation of the economic alternatives are needed before any recommendations can be made.

Large-frequent and large-occasional avalanches, group 3, constitute a small group. Control measures for these avalanches will usually have to be direct protective structures such as avalanche sheds or tunnels.

Group 4 includes all erratic avalanches--small, medium, and large. This group is not very important, and the need for control is not pressing. The small avalanches of this group, however, should be treated with the small ones of the two other groups. This is especially true in the case of possible afforestations because plantations are most likely to succeed where avalanches seldom occur.

If bankslides are included, about half the avalanche areas can be controlled without technical difficulties by building supporting structures and making afforestations in the starting zones. Unfortunately, there are only a restricted number of avalanches where the track or the runout zone can be controlled; terrain conditions favorable to retarding, diversion, or catchment structures are found in only six cases. Avalanche sheds are recommended in 10 cases where large avalanches must be controlled or where terrain conditions are unfavorable for other types of structures.

Table 1.--Physical characteristics and control possibilities of avalanche areas along several mountain highways in Colorado, as inventoried in 1961-62

Physical characteristics and possibilities for structural control	Highway No. and mountain pass						
	No. 40 Berthoud	No. 6 Loveland	No. 160 Wolf Creek	No. 550 Coal Bank Hill	No. 550 Molas Divide	No. 550 Red Mountain	Total
	Number						
BANKSLIDES	0	3	1	1	1	6	12
AVALANCHE GROUPS:							
1. Small-frequent	5	0	1	2	1	8	17
2. Medium-frequent, small-occasional, medium-occasional	2	8	9	1	4	10	34
3. Large-frequent, large-occasional	0	0	1	0	0	5	6
4. Small-, medium-, large-erratic	5	5	1	0	2	10	23
Total	12	13	12	3	7	33	80
POSSIBILITIES FOR STRUCTURAL CONTROL:							
1. Supporting structures in the starting zone--							
Class of structures obvious, no problems, not too expensive	10	6	6	2	5	8	37
Doubtful, difficulties expected, may be expensive and uneconomical	0	2	5	0	1	7	15
Control of starting zone out of question because too difficult, uneconomical, and erratic occurrence	0	3	0	0	0	3	6
2. Structural control in the track or runout zone--							
Favorable terrain conditions	0	1	0	1	1	3	6
Doubtful; may not be very effective	0	1	0	0	0	0	1
3. Direct protection structures--							
Avalanche sheds	0	0	1	0	0	10	11
Avalanche dams	2	0	0	0	0	2	4
Total	12	13	12	3	7	33	80

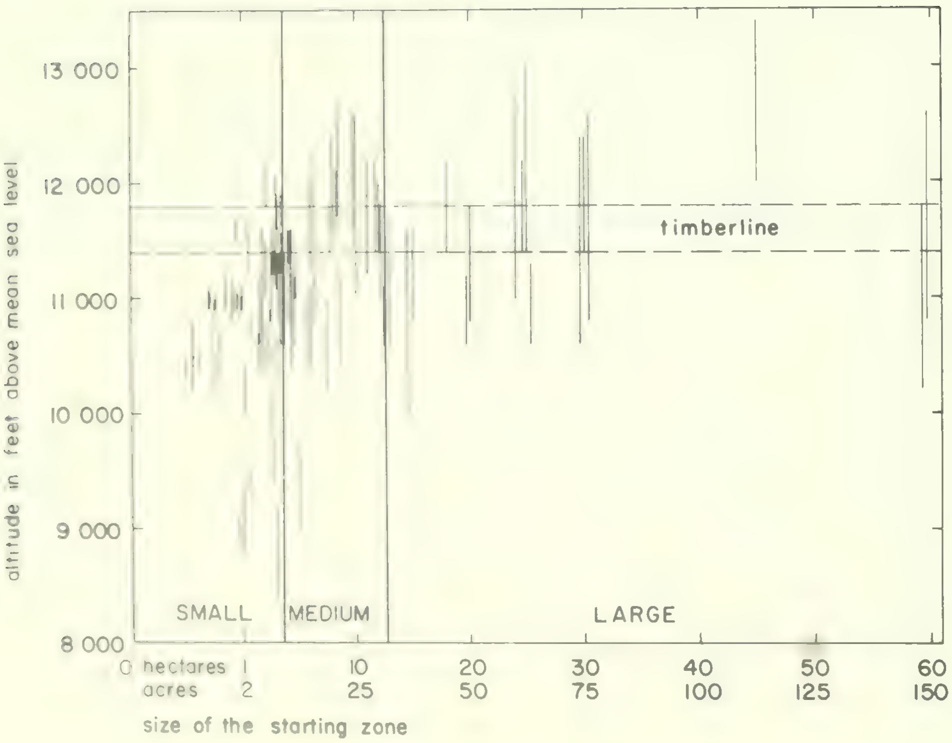


Figure 1.--Size and altitude of the starting zone of 80 avalanches in four mountain passes in Colorado, 1961-62. An expanded scale has been used for the 0- to 2-acre classification.

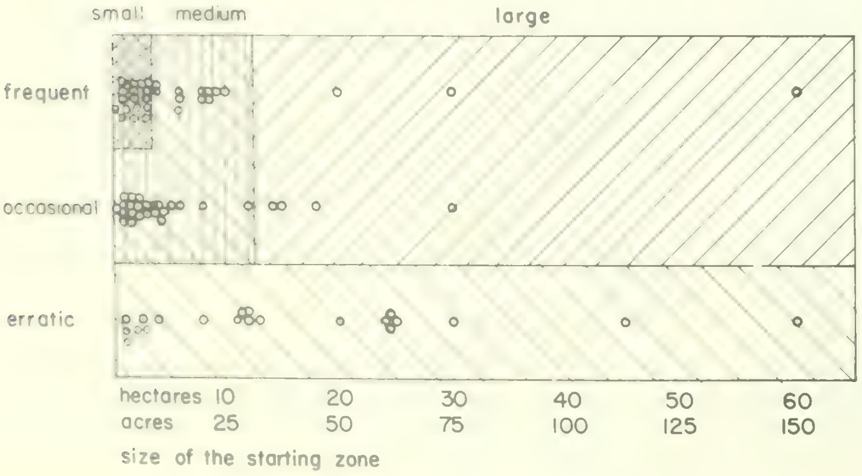
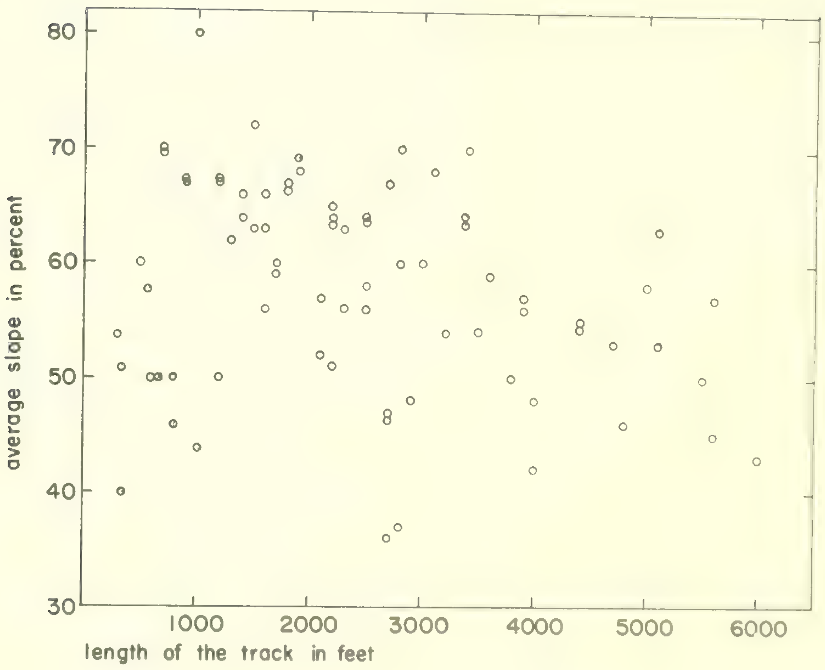


Figure 2.--Frequency of occurrence and size of 80 avalanches in four mountain passes in Colorado, 1961-62. Frequency classifications--erratic, occasional, and frequent--refer to how often the avalanches reach the highway. The size classifications--small, medium, and large--refer to the extent of the starting zone; not to the amount of snow brought down by the avalanche.

Figure 3.--Length and average slope of the tracks of 80 avalanches in four mountain passes in Colorado, 1961-62.

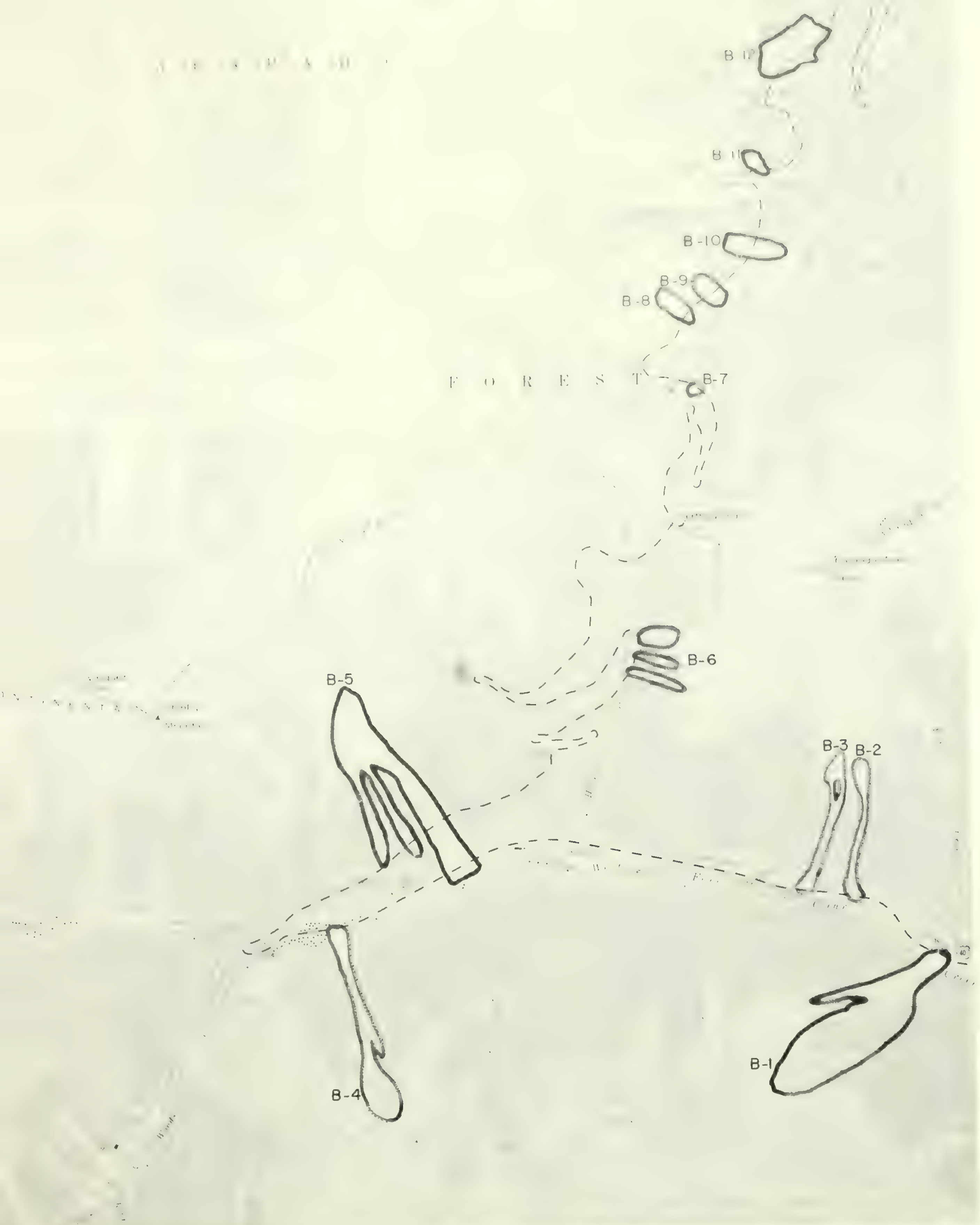


GENERAL PLANNING FOR STRUCTURAL CONTROL

Structural avalanche control should be started in areas where it is obvious what class of structural control will work, and where control measures will not be too expensive for the values involved. A group of neighboring avalanches should be considered as a single unit for control purposes. Control plans for any one of the group should be part of a more comprehensive project designed for controlling the entire group.

Enough time should be allowed to study the winter terrain conditions of all doubtful cases. Structural avalanche defenses cannot be started in a day; careful winter observations are necessary to do a good job. In areas where supporting structures will be built, observations of snow conditions in the starting zone should be started as soon as possible. Where avalanche sheds are being considered, a close inspection of winter conditions in the runout zone is necessary. Of course, for any avalanche defense planning, records of frequency, size, and type of avalanches are very important and should be continued even after the structures are installed.

Structural control does not stop with the completion of the structures. Maintenance of the structures is vital and never ending. Later adjustments or additions will often have to be made to insure complete protection.


B 12
B 11
B-10
B-9
B-8
FOREST
B-7
B-6
B-5
B-3
B-2
B-1
B-4

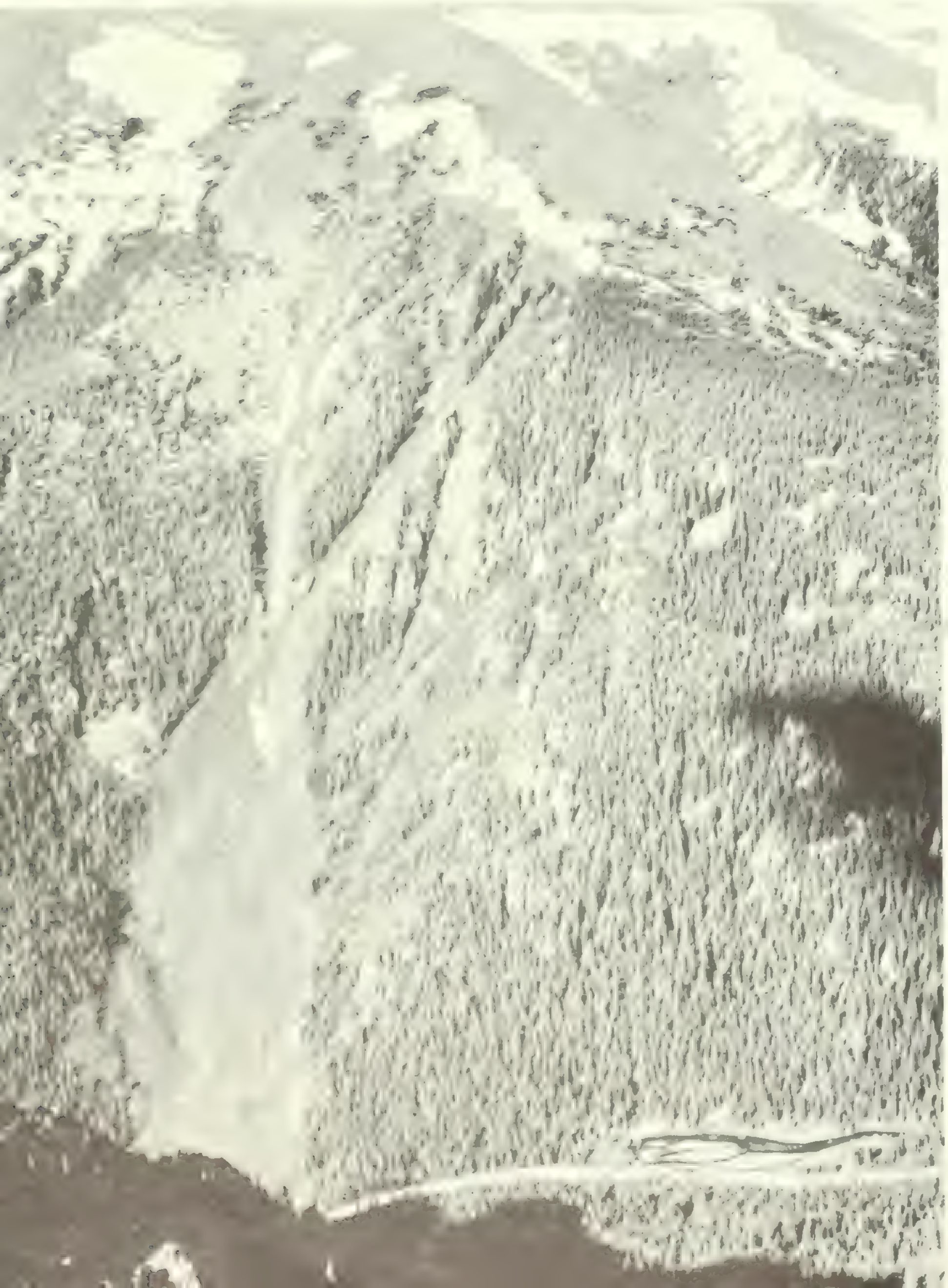
SUMMARY FOR HIGHWAY No. 40: BERTHOUD PASS

Berthoud Pass has large avalanches on the south side only. The snowslides on the north side, essentially large bankslides, run in spots where fire denuded the slopes. A few small plantations have been established in these areas.

Of the six avalanches on the south side, four are on the same slope as the highway. ASPEN and CAMPGROUND reach the road so seldom they need not be controlled. FLORAL PARK can be easily controlled with lightweight supporting structures and afforestation. STANLEY is the only avalanche for which structural control will require much effort. The other two avalanches, DAM and BERTHOUD FALLS, run down the slope across the valley from the highway and reach the road only under very severe conditions.

The six avalanches on the north side are small and easily accessible. Control with supporting structures and more extensive afforestation is recommended.

Of the five mountain passes considered in this report, structural protection against avalanches would be easiest on Berthoud Pass.



Highway No. 40 --
Berthoud Pass
Photo: June 19, 1962

DAM (B-1)

LOCATION:
Front Range; Berthoud Pass south; northeast slope of the east shoulder of Engelmann Peak.

CATCHMENT BASIN:
A V-shaped depression in the slope; above and below timberline; 11,800-10,800 feet m.s.l.; 50 acres (20 ha).

TRACK:
Gully; vertical drop, 2,120 feet; length, 3,600 feet; average slope, 59 percent.

RUNOUT ZONE:
Lower section of gully, Clear Creek valley bottom, and opposite slope where highway lies. Highway is 40 feet above Clear Creek and 200 feet away from it. Runout zone in lower section of gully; length, 1,500 feet; average slope, 27 percent. Usually, avalanches stop on this gentle section or in bed of Clear Creek. Large avalanches, however, reach highway and beyond.

AVALANCHES:
Avalanche, shot down April 8, 1957, ran to highway; killed two men.

CLASSIFICATION:
Large-erratic. Erratic designation relates to frequency with which avalanche reaches highway, not to frequency of runs below road.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Parts of catchment basin are rugged with cliffs, starting area is large. Control of starting zone would be expensive. If structural control is undertaken, a very large catchment dam between Clear Creek and highway might be a solution.

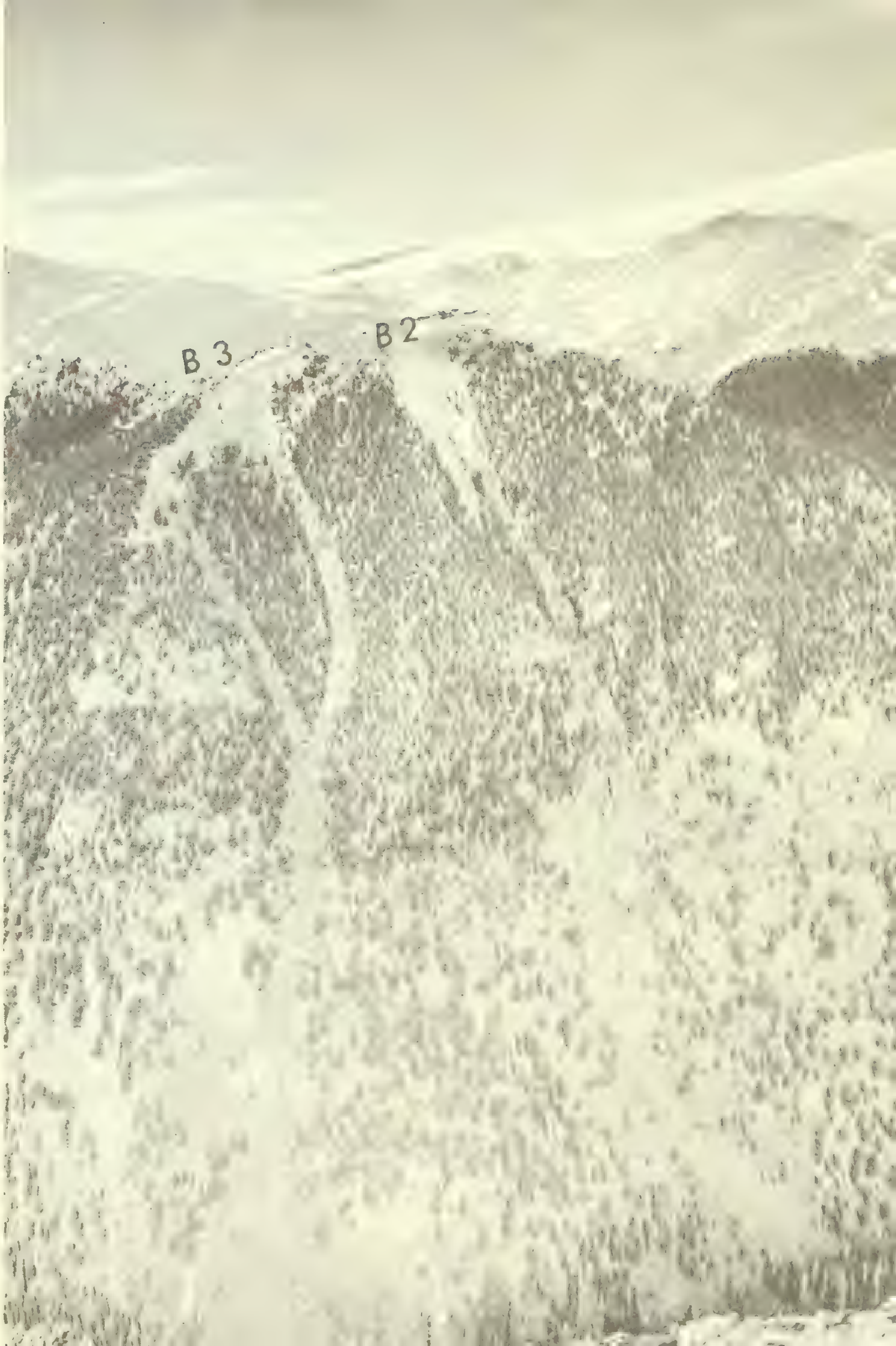
Highway No. 40 --
Berthoud Pass
Photo: November 14, 1963

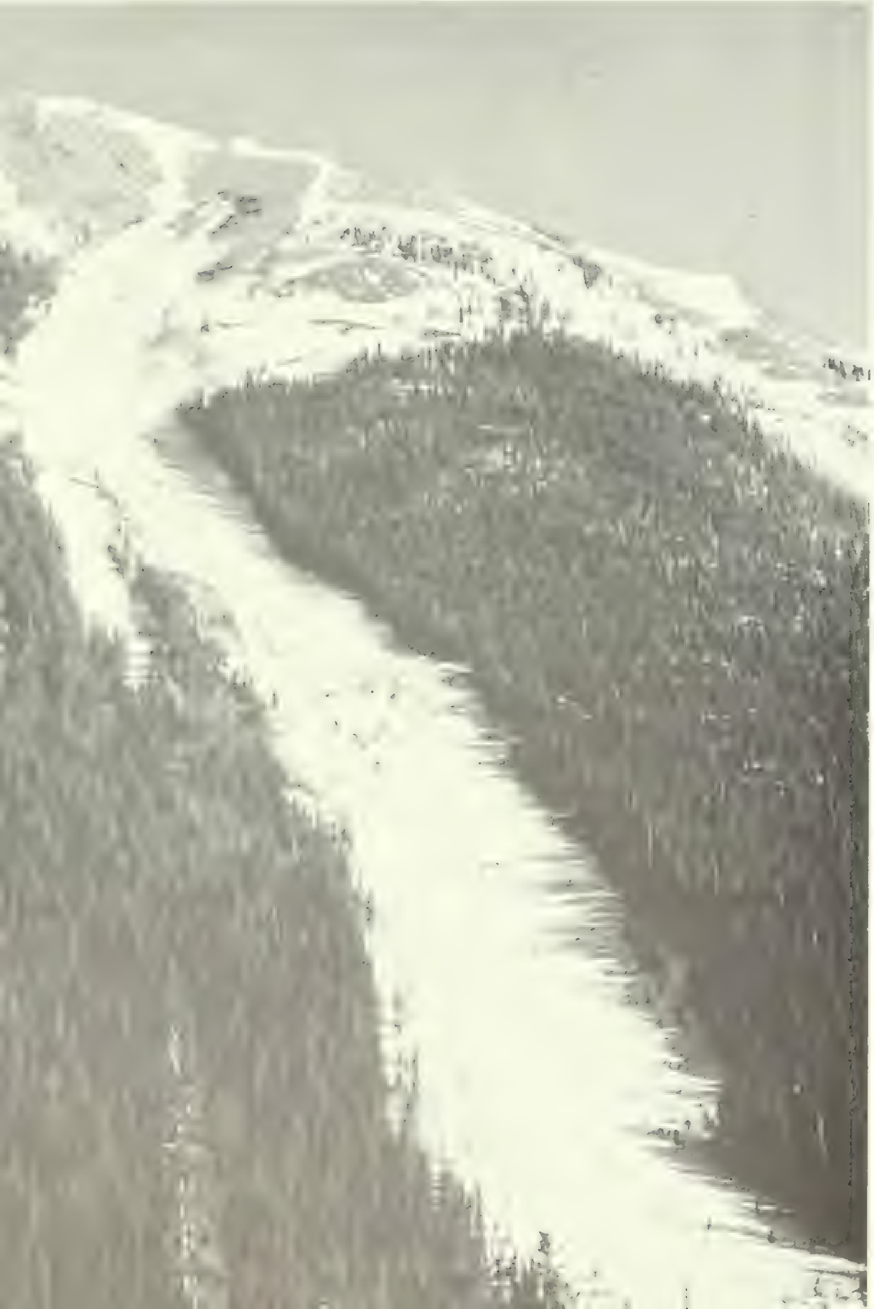
ASPEN (B-2)

LOCATION:
Front Range; Berthoud Pass south; south slope of Colorado Mines Peak.
CATCHMENT BASIN:
Depression in slope at upper end of an ephemeral stream; mostly below timberline; 11,600-11,000 feet m.s.l.; 4 acres (2 ha).
TRACK:
Steep narrow gully; vertical drop, 2,160 feet; length, 3,400 feet; average slope, 63 percent.
RUNOUT ZONE:
Above road, 300-400 feet long; average slope, 35 percent.
CLASSIFICATION:
Small-erratic.
POSSIBILITIES FOR STRUCTURAL CONTROL:
Supporting structure in starting zone and afforestation. Snowfences on slope to windward of catchment would reduce snow depths in catchment and might help natural reforestation.

CAMPGROUND (B-3)

LOCATION:
Front Range; Berthoud Pass south; south slope of Colorado Mines Peak; 1,000 feet west of ASPEN avalanche track.
CATCHMENT BASIN:
Lee side of a small ridge; mostly below timberline; 11,600-11,200 feet m.s.l.; 5 acres (2 ha).
TRACK:
Two narrow slots in timber merging part way down the ridge; vertical drop, 2,120 feet; length, 3,400 feet; average slope, 62 percent.
RUNOUT ZONE:
Above road, 500 feet long; average slope, 30 percent.
CLASSIFICATION:
Small-erratic.
POSSIBILITIES FOR STRUCTURAL CONTROL:
Supporting structures in starting zone and afforestation. Snowfences to windward of catchment area might help trees get started by reducing snow depths.





Highway No. 40 --
Berthoud Pass
Photo: April 23, 1962

BERTHOUD FALLS (B-4)

LOCATION:
Front Range; Berthoud Pass south; north face of north spur of Engelmann Peak.

CATCHMENT BASIN:
A bowl-shaped depression on slope; above timberline; 12,200-11,200 feet m.s.l.; 27 acres (11 ha).

TRACK:
Gullylike depression in slope; avalanches have cut a slot in heavy timber; vertical drop, 2,200 feet; length, 3,900 feet; average slope, 57 percent.

RUNOUT ZONE:
Gentle section of lower track and Clear Creek valley bottom. Highway lies on opposite slope 30 feet above and 380 feet beyond Clear Creek. Although there are no records of this avalanche ever having reached the highway, it is possible. Normally, avalanches stop before reaching Clear Creek, in gentle section of lower track which is 700 feet long with average slope of 36 percent.

AVALANCHES:
For many years this avalanche has not given trouble to the highway.

CLASSIFICATION:
Medium-erratic.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Since avalanche very seldom runs to highway, need for structural control is questionable. Technically speaking, supporting structures in starting zone as well as a catchment dam near highway would be possible.

Highway No. 40 --
Berthoud Pass
Photo: June 18, 1962

STANLEY (B-5)

LOCATION:
Front Range; Berthoud Pass south; southeast slope of the east shoulder of Stanley Mountain. The top of the avalanche area (ridge face southeast of point 12,507) is erroneously called "Stanley Mountain" by local people. Stanley Mountain is actually 1 mile farther west.

CATCHMENT BASIN:
A bowl-shaped depression on the slope; above timberline; 12,400-11,600 feet m.s.l.; 20 acres (8 ha).

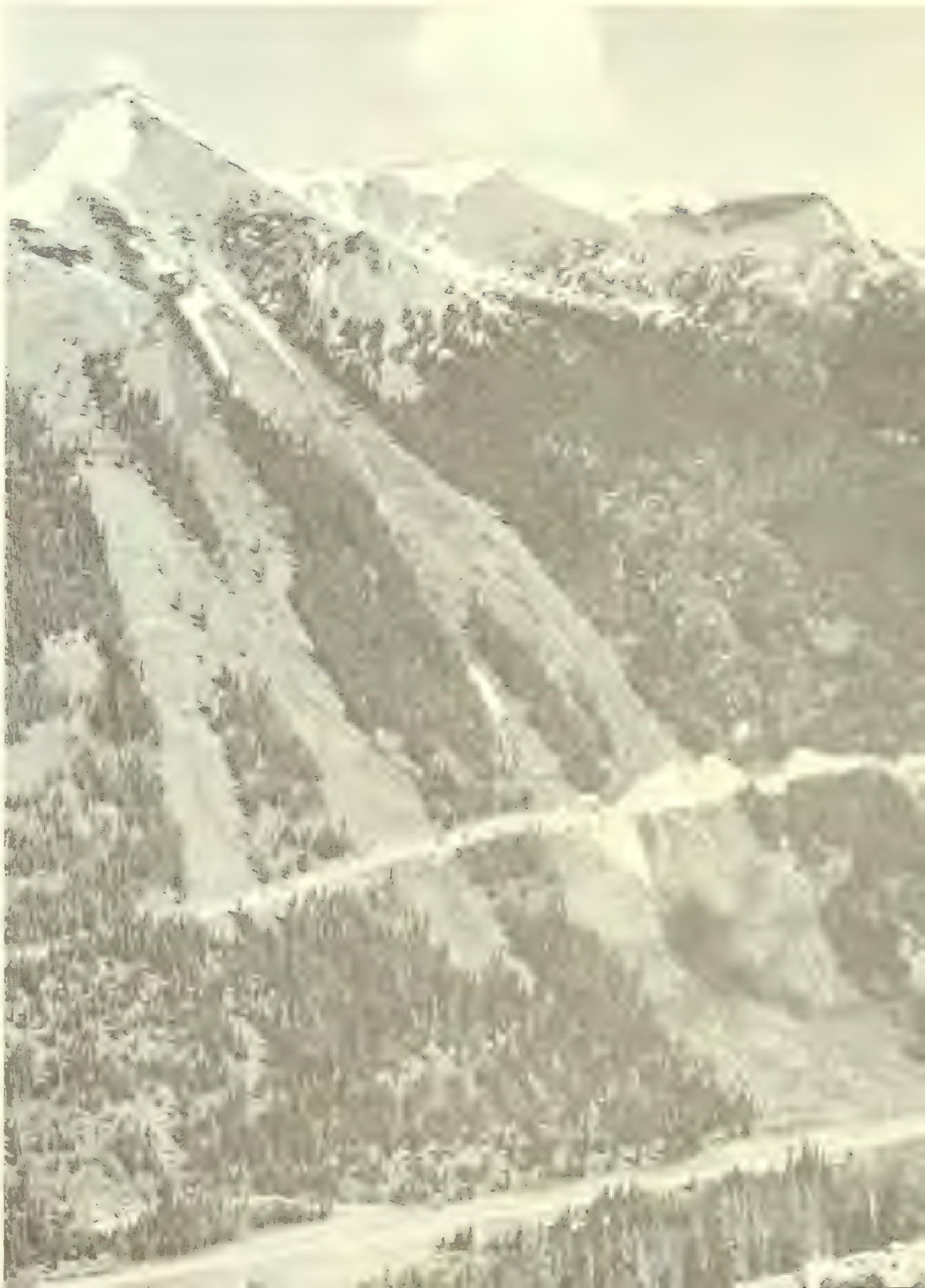
TRACK:
Not confined; three slots in timber; vertical drop, 2,400 feet; length, 4,400 feet; average slope, 55 percent.

RUNOUT ZONE:
Lower section of the track with a more gentle slope and valley bottom of Clear Creek; length, 900 feet; average slope, 33 percent. Width of track and runout zone, 2,000 feet.

AVALANCHES:
Blocked the highway on the following dates: February 6, 1951; December 30, 1951; January 28, 1955; February 16, 1956; January 22, 1959; February 4, 1960; March 3, 1960; February 28, 1961; January 21, 1964; and March 6, 1964. Avalanches ran but did not reach the highway on February 6, 1959, December 19, 1960, December 27, 1961, January 23, 1963, and February 25, 1963.

CLASSIFICATION:
Medium-frequent.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Structural controls in the catchment basin or an avalanche shed are the two possibilities. A detailed study has been made of the possibility for structural control of this avalanche.[10]



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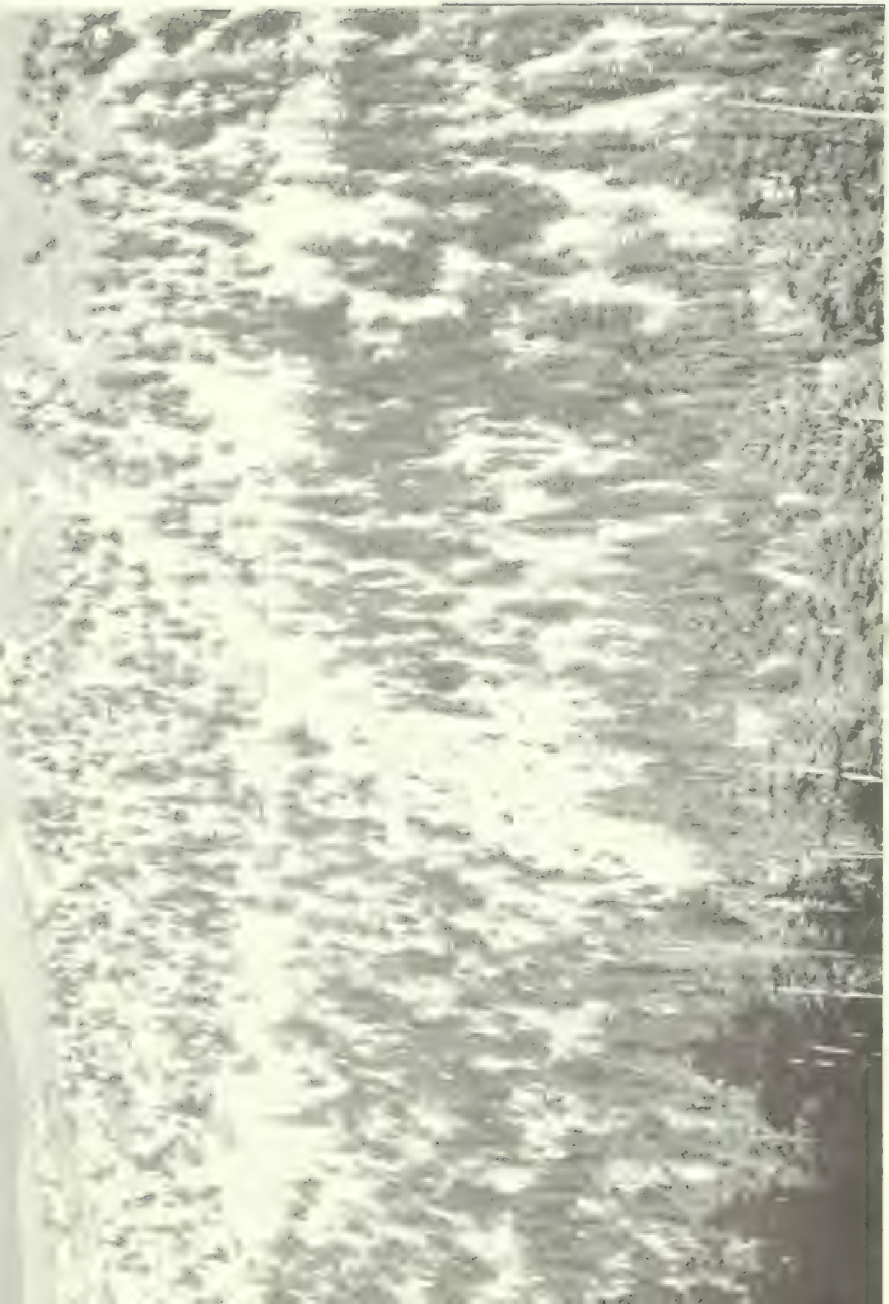
[10] *See footnote 6, p. 8.*



Highway No. 40 --
Berthoud Pass
Photo: April 23, 1962

FLORAL PARK (B-6)

LOCATION:
Front Range; Berthoud Pass south; west slope of Colorado Mines Peak.

STARTING SPOTS:
On steep, sparsely timbered slopes with local snowdrifts; starting areas are not well defined; below timberline; 11,600-11,300 feet m.s.l.; 10 acres (4 ha).

TRACKS:
Slight depressions in the slope or through the trees: indefinite; vertical drop, 920 feet; length, 1,400 feet; average slope, 66 percent.

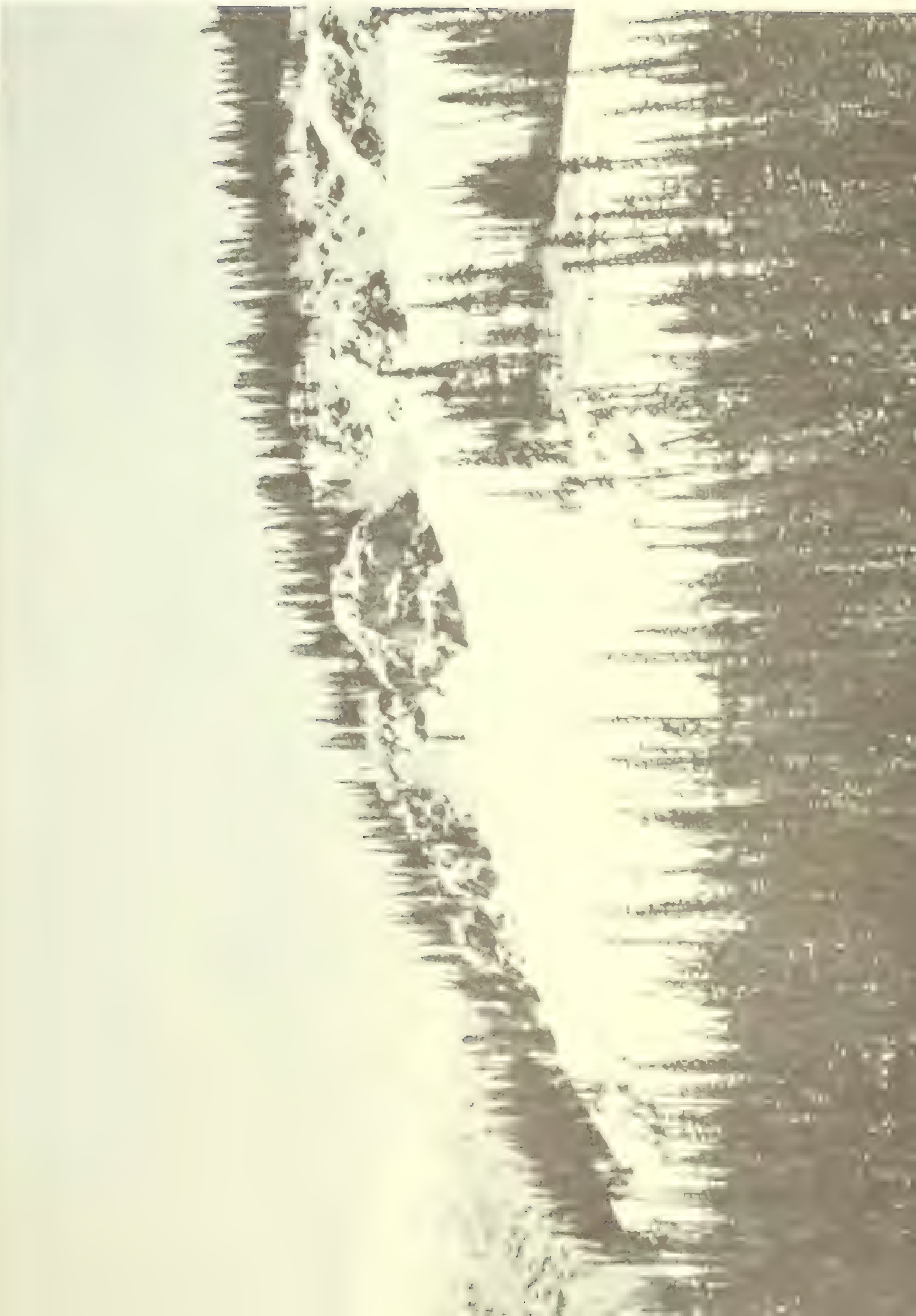
RUNOUT ZONE:
No transition zone above highway; avalanches cross the highway and run out into the flat bottom of Hoop Creek just below the highway.

AVALANCHES:
Ran to the highway on: December 30, 1951 (caught a car); April 1, 1957; February 16, 1958; April 18, 1958; February 15, 1960; March 21, 1961; and January 7, 1962.

CLASSIFICATION:
Medium-frequent.

POSSIBILITIES FOR STRUCTURAL CONTROL:
No problems for control in the starting spots. Afforestation of the openings in the timber is the most important part of the control work. Lightweight supporting structures will be needed to control the area, however, until the trees are large enough to stabilize the snow.

Highway No. 40 --
Berthoud Pass
Photo: Date unknown



EIGHTY (B-7)

LOCATION:
Front Range; Berthoud Pass north; starts about 200 feet north of first switchback on north side of Berthoud Pass.

CATCHMENT BASIN:
Three small, rocky slots; below timberline; 11,000 feet m.s.l.; 1 to 2 acres (less than 1 ha).

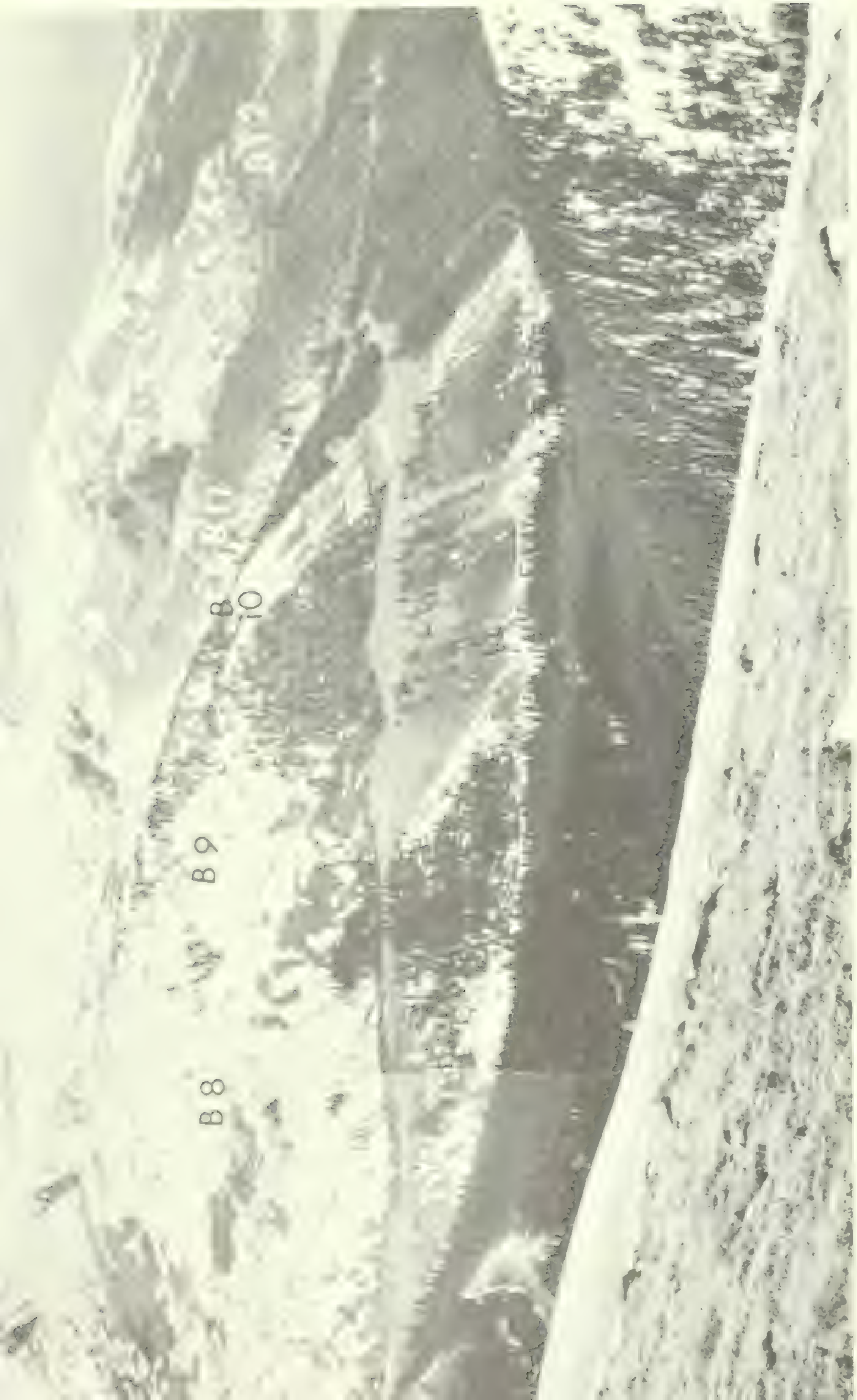
TRACK:
Uniform, open talus slope; vertical drop, 160 feet; length, 300 feet; average slope, 53 percent.

RUNOUT ZONE:
None. Drops over cut bank onto the highway.

AVALANCHES:
Has run at least 6 times in the last 9 years.

CLASSIFICATION:
Small-frequent. This is essentially a large bankslide.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Access is easy, so supporting structures would present no problem. Afforestation may be difficult on the talus.



Highway No. 40 --
Berthoud Pass
Photo: April 23, 1963

(NORTH SIDE GROUP)

ONE-TEN (OR WEICKER) (B-8)

LOCATION:
Front Range; Berthoud Pass north; southeast slope of point 11,721 between Current Creek and Second Creek.

STARTING ZONE:
Open slope with scattered small trees; some small rocky outcroppings; below timberline; 11,100-11,000 feet m.s.l.; 3-4 acres (less than 2 ha).

TRACK:
Open, uniform slope denuded of trees by fire; vertical drop, 440 feet; length, 1,000 feet; average slope, 44 percent.

RUNOUT ZONE:
None above road.

AVALANCHES:
Has run at least twice in past 9 years.

CLASSIFICATION:
Small-frequent. This is essentially a large bankslide.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Structures plus afforestation. Access is very simple.

ONE-TWENTY (B-9)

LOCATION:
Front Range; Berthoud Pass north; southeast slope of point 11,721 between Current Creek and Second Creek; 1,000 feet north of slide 110.

CATCHMENT BASIN:
Open slope with scattered small trees; below timberline; 11,000 feet m.s.l.; 1 acre (1/2 ha).

TRACK:
Open slope. Vertical drop, 320 feet; length, 700 feet; average slope, 46 percent.

RUNOUT ZONE:
No transition above road. Snow comes over cut bank to the highway.

CLASSIFICATION:
Small-frequent. Another large bankslide.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Easy access makes structure and afforestation the obvious choice.

ONE-FORTY (B-10)

LOCATION:
Front Range; Berthoud Pass north; on the eastern flank of point 11,721 between Current Creek and Second creek; 1,500 feet north of avalanche 120.

CATCHMENT BASIN:
Open, uniform slope with scattered trees. 11,000 feet m.s.l.; 1 acre (1/2 ha).

TRACK:
Broad area on the point of the ridge about 400-500 feet wide. Vertical drop, 300 feet; length, 600 feet; average slope, 50 percent. Lower part of the track was steepened considerably in 1960 when material was removed to be used as fill for the highway.

RUNOUT ZONE:
None. Snow falls into a large barrow pit dug to get fill material for the highway. This pit will probably stop the slide before it reaches the highway.

AVALANCHES:
Past records will not apply now that there is a large barrow pit between the highway and the avalanche. Earthen terraces in the track.

CLASSIFICATION:
Small-frequent avalanche or large bankslide.

POSSIBILITIES FOR STRUCTURAL CONTROL:
This area should be checked carefully for a few years, but it seems likely that the barrow pit will protect the road. If more control is needed, the upper part of the track could be controlled with structures and afforestation. Earthen terraces in the track failed to keep avalanches out of the road.

TWO HUNDRED (OR MONUMENT) (B-11)

LOCATION:
Front Range; Berthoud Pass north; the south-facing bank just north of Second Creek.

CATCHMENT BASIN:
Open slope with scattered trees; indefinite starting zone - approximately 10,700 feet m.s.l.; 1-2 acres (1/2 ha).

TRACK:
Open slope 200-400 feet wide. Vertical drop, 100 feet; length, 200-300 feet; average slope, 40 percent.

RUNOUT ZONE:
None above the road.

CLASSIFICATION:
Small-erratic avalanche or large bankslide.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Afforestation protected by supporting structures.

Highway No. 40 --
Berthoud Pass
Photo: Date unknown

TWO-FORTY (B-12)

LOCATION:
Front Range; Berthoud Pass north; about 1,000 feet north of First Creek.

CATCHMENT BASIN:
Open slope with scattered small trees; below timberline; 10,800 feet m.s.l.; 2-1/2 acres (1 ha).

TRACK:
Open slope. Vertical drop, 400 feet; length, 700 feet; average slope, 57 percent.

RUNOUT ZONE:
Below highway.

CLASSIFICATION:
Small-erratic avalanche or large bankslide with scattered small trees in parts of it.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Supporting structures plus afforestation. Access is easy.

SUMMARY FOR HIGHWAY No. 6: LOVELAND PASS

Avalanches along Highway No. 6, may be classified into seven groups based on their proximity, and on similarity of recommended control measures. The individual avalanches within each group can be treated separately, but the entire group should be handled as a single control project.

Group 1: Silver Plume--PINKERTON GULCH, SILVER CLOUD, BARD SHOULDER
Group 2: BETHEL
Group 3: SEVEN SISTERS
Group 4: GRIZZLY
Group 5: North Arapaho--LITTLE PROFESSOR, ASSOCIATED LITTLE PROFESSOR, BLACKWIDOW
Group 6: PALLAVICINI
Group 7: Afforestations -- LAZY SUSAN, FIVE CAR, HAPPY END.

As far as avalanche hazard is concerned, the Seven Sisters, Bethel, and North Arapaho groups are the most important. Control by supporting structures and afforestation is indicated for the Seven Sisters, but may not be economical for the North Arapaho and Bethel groups. For these two groups, avalanche sheds might be more economical.

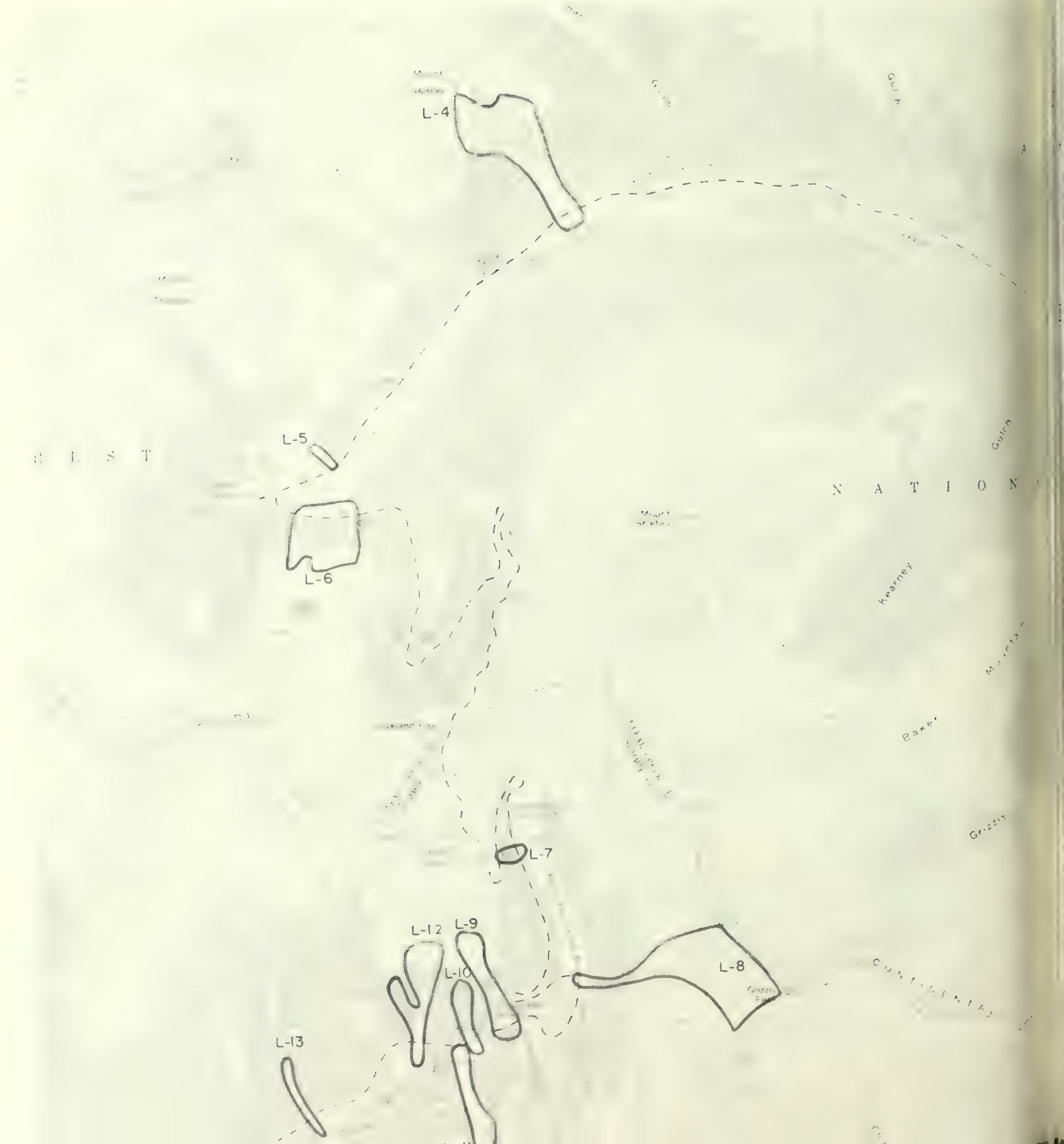
The Silver Plume and Grizzly groups are all medium to large avalanches of erratic to very erratic occurrence. The control of these two groups can probably be postponed unless the new road through Straight Creek moves the highway closer to these avalanches.

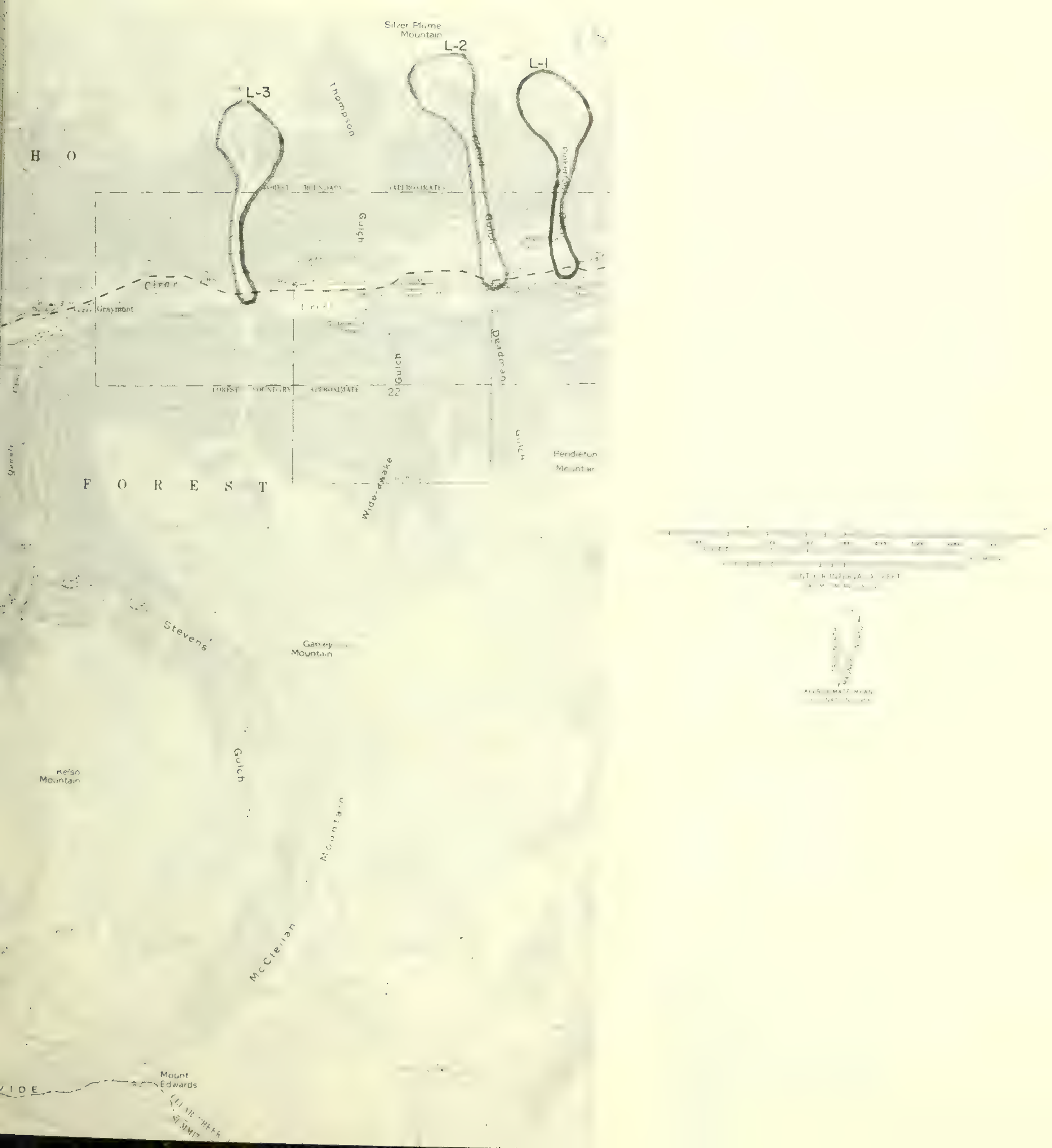
Group 6, Pallavicini, is a special case. Control by structures in the starting zone would be possible, but, because of ski use, this type of control is not very likely.

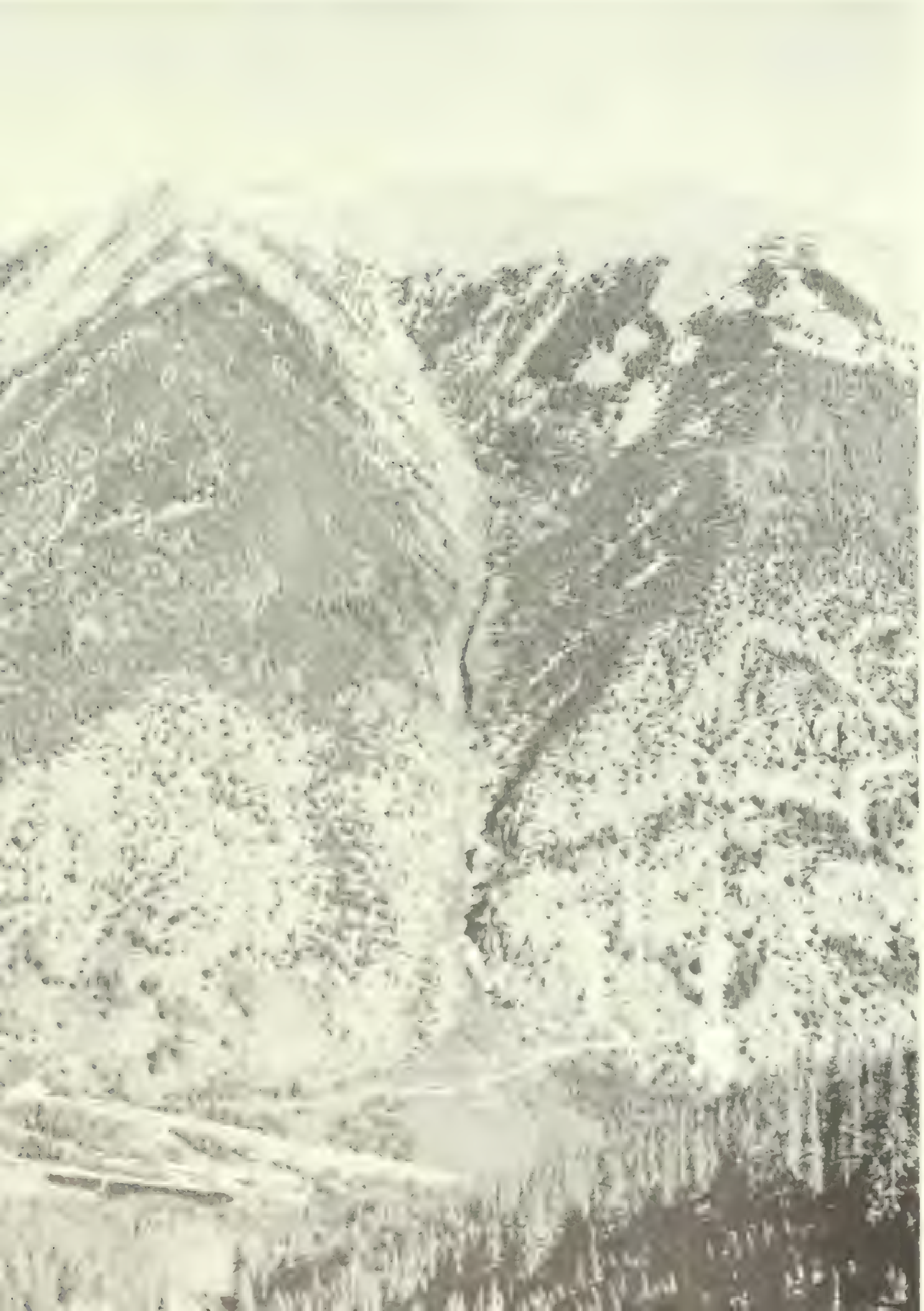
All avalanches in Group 7 (Afforestation) are small and can certainly be controlled by supporting structures supplemented by afforestation of the starting zone and the track.

Since structural avalanche control, especially in the starting zone, is something new in this region, projects should begin with the easier cases and not with the larger and more difficult ones. Some experience must be gained, first, and that can be done with less risk on little projects.

When the tunnel is completed through the Continental Divide from Clear Creek to Straight Creek, Bethel and Silver Plume groups will become very important. On the other hand, since this means the heavy traffic will no longer be subjected to the hazard of the other groups, there would be a good opportunity to start some experimental defense works in these areas. If the old highway over Loveland Pass is kept open, the SEVEN SISTERS and LITTLE PROFESSOR would be excellent study sites.


L-4
L-5
E S T
L-6
N A T I O N
Gulch
Kearney
Mountain
Baker
Grizzly
L-7
L-12
L-9
L-10
L-8
CONTINENTAL
L-13


Silver Plume Mountain
L-2
L-1
L-3
Thompson
H O
Gulch
Gulch
Clear
Graymont
Creek
Gulch
22
Quadrant
Gulch
Pendleton Mountain
F O R E S T
Wide-awake
Stevens
Gibney Mountain
Gulch
Kelso Mountain
Mountain
McClellan
Mount Edwards
IDE



Highway No. 6 --
Loveland Pass
Photo: September 1, 1962

PINKERTON GULCH (L-1)

LOCATION:
Front Range; south slope of Silver Plume Mountain.

CATCHMENT BASIN:
Bowl-shaped depression in the south-facing slope; above and below timberline; 12,000-11,400 feet m.s.l.; 30 acres (12 ha).

TRACK:
Pinkerton Gulch; vertical drop, 2,400 feet; length, 4,400 feet; average slope, 55 percent.

RUNOUT ZONE:
The alluvial fan of Pinkerton Gulch; length, 1,000 feet; width, 700 feet; average slope, 30 percent. Distance from the mouth of Pinkerton Gulch to the highway is 800 feet. The avalanche snow is confined when it reaches the alluvial fan.

AVALANCHES:
The last one occurred in spring, 1957.

CLASSIFICATION:
Medium-erratic.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Because it runs only in very severe winters, structures would not be economical. There are no difficulties for supporting structures. The possibilities of control in the runout zone are very limited because this zone is too short and too steep to build effective retarding or catchment structures.

Highway No. 6 --
Loveland Pass
Photo: September 1, 1962

SILVER CLOUD (L-2)

LOCATION:
Front Range; south slope of Silver Plume Mountain.

CATCHMENT BASIN:
Bowl-shaped depression in the south-facing slope; above and below timberline; 12,400-11,400 feet, m.s.l.; 75 acres (30 ha).

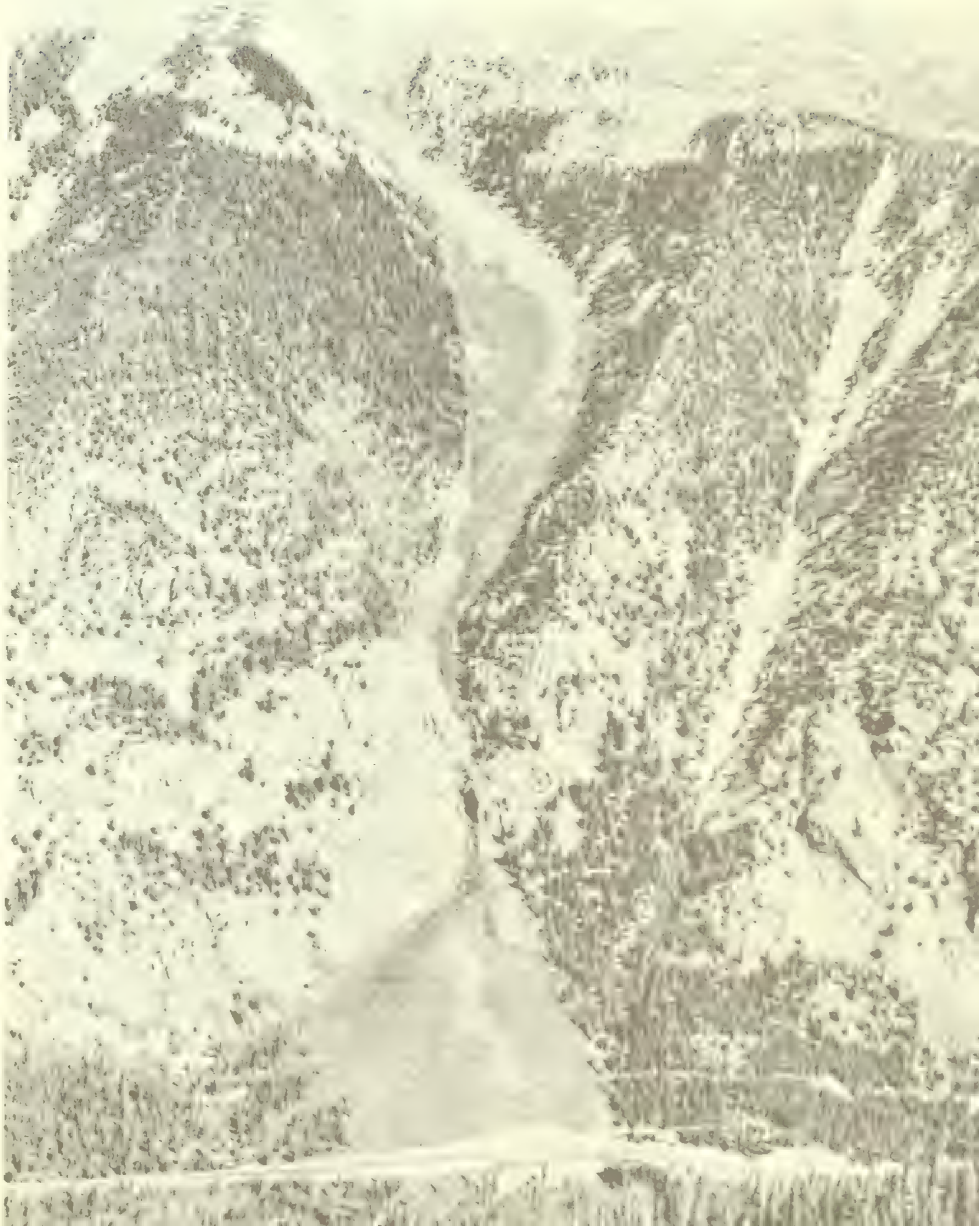
TRACK:
Cloud Gulch; vertical drop, 2,700 feet; length, 5,500 feet; average slope, 50 percent.

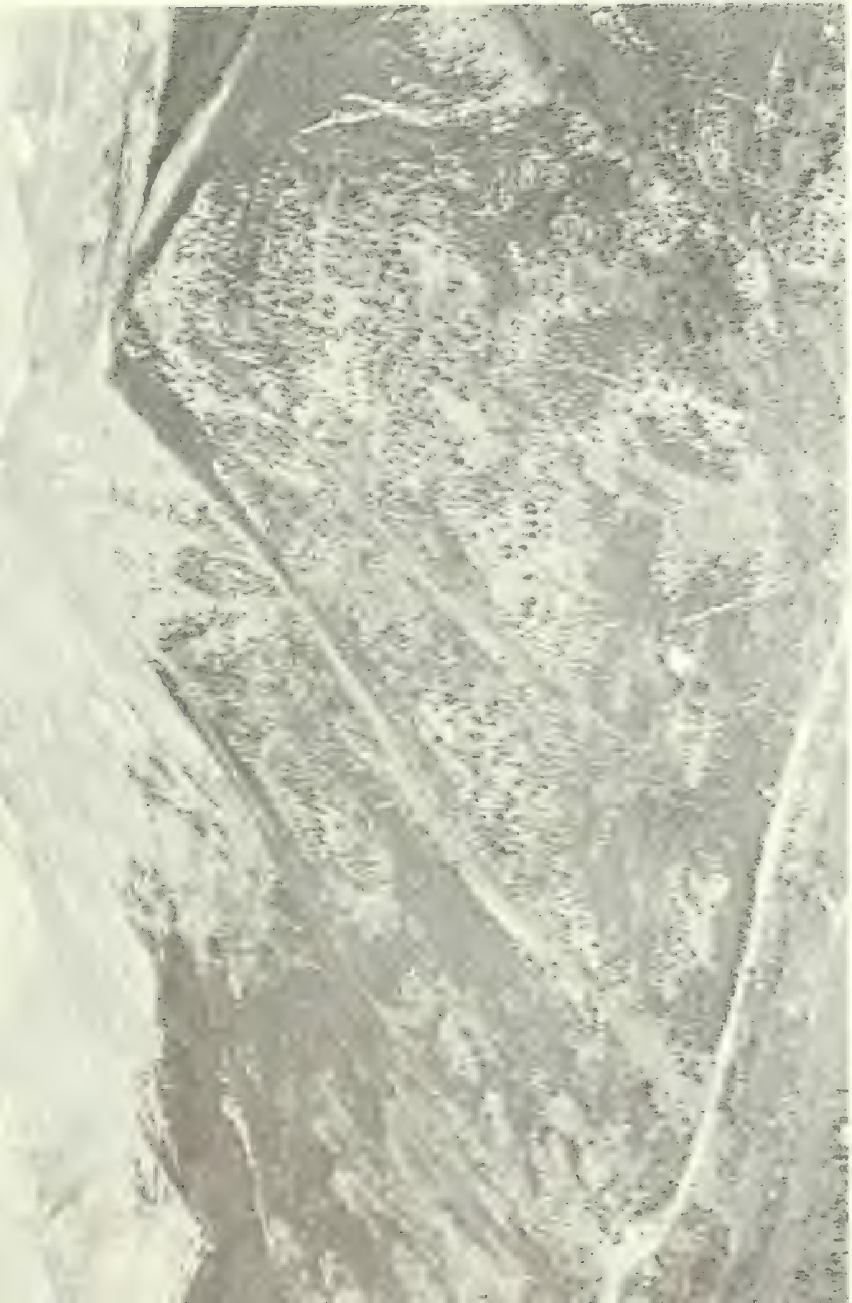
RUNOUT ZONE:
Alluvial fan of Cloud Gulch, the slope of which varies from very gentle to moderate. Avalanche will be unconfined on the fan. Distance from the mouth of the gulch to the highway is 900 feet; width of the fan where it reaches the highway is 1,500 feet; the fan has an average slope of 25 percent.

AVALANCHES:
On April 12, 1951, an avalanche reached the highway.

CLASSIFICATION:
Large-erratic.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Because it is an erratic, large avalanche, structural control seems to be not very economical, especially supporting structures. The runout zone offers some possibilities for the installation of retarding structures. Whether such control is possible can be answered only by a detailed study of the frequency of occurrence and the terrain conditions in the runout zone.





Highway No. 6 --
Loveland Pass
Photo: September 1, 1962

BARD SHOULDER (L-3)

LOCATION:
Front Range; south slope of southeast end of the Bard Peak Shoulder.

CATCHMENT BASIN:
Bowl-shaped depression in the south-facing slope; rugged and very steep in places; above and below timberline; 12,200-11,400 feet m.s.l.; 30 acres (12 ha).

TRACK:
Unnamed gulch; vertical drop, 2,200 feet; length, 3,900 feet; average slope, 56 percent.

RUNOUT ZONE:
Gentle slope in the lower section of the gulch; width, 500 feet; length, 1,100 feet; average slope, 35 percent.

CLASSIFICATION:
Medium-very erratic.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Because of the ruggedness of the starting zone, the steepness of the track, and the steep runout zone, successful control by either supporting structure or retarding structure seems quite unlikely. Since the avalanche occurs very seldom, control is not pressing.

Highway No. 6 --
Loveland Pass
Photo: June 18, 1962

BETHEL (L-4)

LOCATION:
Front Range; southeast slope of Bethel Mountain.

CATCHMENT BASIN:
A bowl-shaped depression in the slope on the west, and steep regular slope on the east; both above timberline; 12,600-11,000 feet m.s.l.; 25 acres (10 ha).

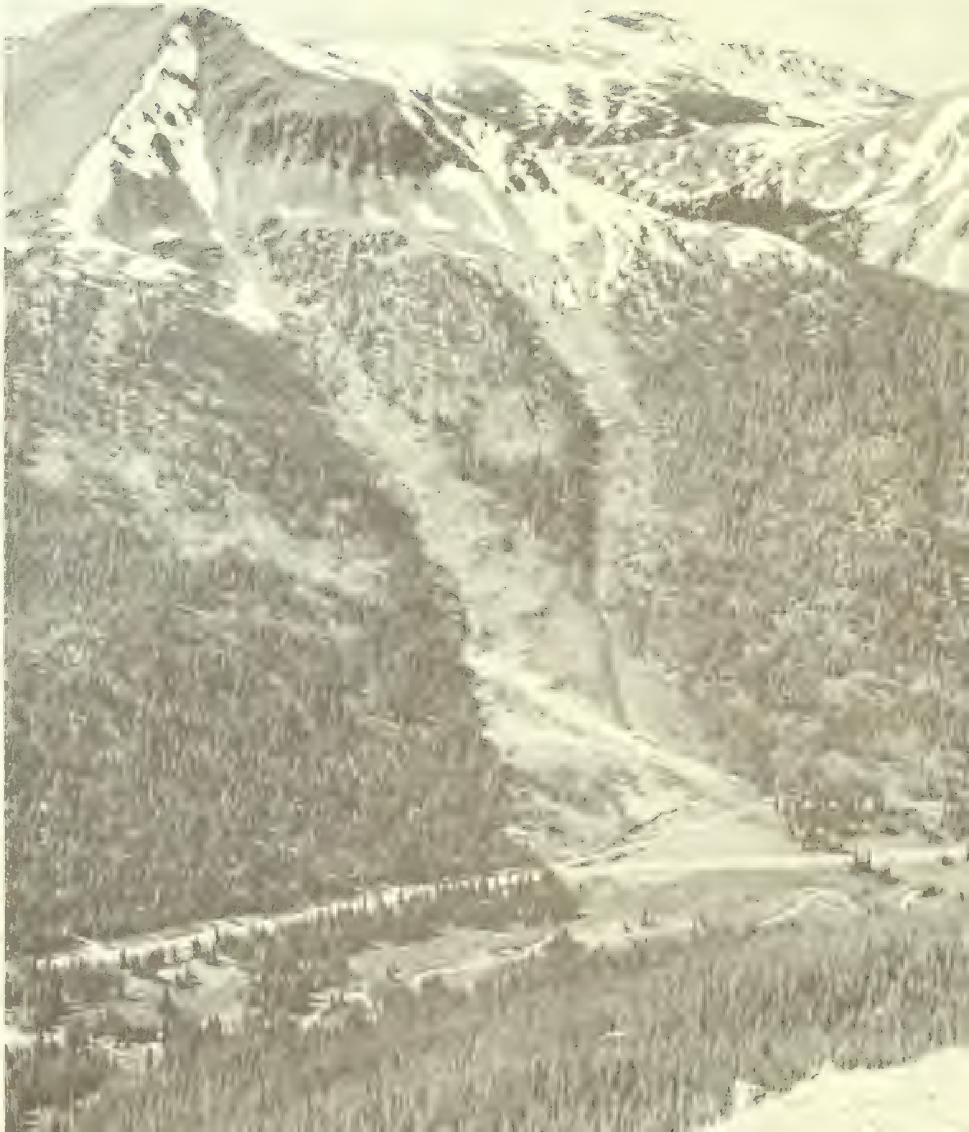
TRACK:
The tracks from the two separate catchment basins join at an elevation of about 10,800 feet. These two tracks are gullylike. The main avalanche is the one that starts in the bowl-shaped depression; vertical drop, 1,800 feet; length, 3,000 feet; average slope, 60 percent.

RUNOUT ZONE:
The lowest section of the main track. This slope is 1,100 feet long, 700 feet wide, with an average slope of 40 percent.

AVALANCHES:
Runs to the road about once every 2 years.

CLASSIFICATION:
Medium-frequent.

POSSIBILITIES FOR STRUCTURAL CONTROL:
The ruggedness and steepness of the catchment basin, together with the excessive snow accumulations (drifts), create some problems for supporting structures. Two diversion dams already installed, are not always effective because the runout zone is too steep and the dams too small. Control measures either in the track or in the runout zone are out of the question if full protection is expected from all avalanches. Only very expensive supporting structures or an avalanche shed would give full protection to the road. Guide walls parallel to the avalanche track could be used with an avalanche shed to shorten the length of the expensive shed.



Highway No. 6 --
Loveland Pass
(No photo)

LAZY SUSAN (L-5)

LOCATION:
Front Range; southeast slope, one-third mile below the parking lot for the Loveland Basin ski area.

CATCHMENT BASIN:
Little cliffs in an area of scattered timber, at an altitude of 11,000 feet m.s.l.; 2-1/2 acres (1 ha).

TRACK:
Poorly defined in scattered timber. Vertical drop, 300 feet; length, 600 feet; average slope, 50 percent.

RUNOUT ZONE:
No transition zone, track hits highway directly.

AVALANCHES:
Has run to the road at least twice in past 10 years. New highway construction is going through this area and will alter conditions considerably.

CLASSIFICATION:
Small-occasional.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Some starting points in the cliffs may cause difficulty for structural control. However, the small starting zone and the fact that it lies in a generally timbered area would render control with supporting structures easy and economical. Afforestation in connection with some protecting structures should be studied immediately.

Highway No. 6 --
Loveland Pass
Photo: May 10, 1962

SEVEN SISTERS (L-6)

LOCATION:
Front Range; north slope near Loveland Basin ski area.

CATCHMENT BASINS:
At and below timberline; north slope 11,800-11,400 feet m.s.l. There are seven small, bowl-shaped starting zones that are separated by timbered ridges. The whole starting area of all seven avalanches is about 20 acres (8 ha).

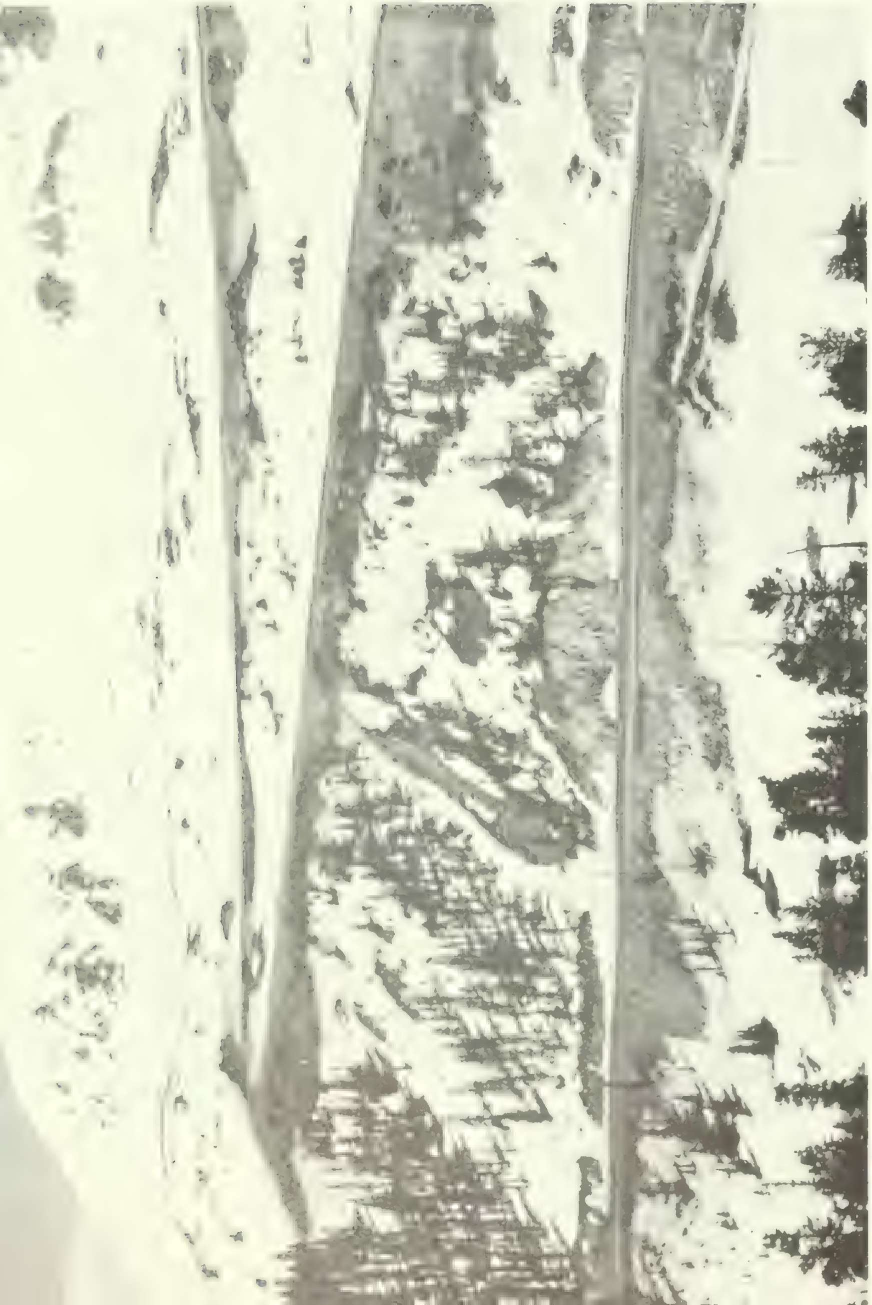
TRACKS:
Seven gullylike tracks on a timbered slope; vertical drop, 900 feet; length, 1,400 feet; average slope, 64 percent.

RUNOUT ZONE:
No transition zone between the tracks and the highway. The avalanches, after filling the road cut with snow, travel across the road down to Clear Creek.

AVALANCHES:
Very frequent; usually released four to six times a winter by artillery fire. Avalanche cycles are recorded as early as mid-November and as late as the end of April.

CLASSIFICATION:
A group of seven, small-frequent avalanches.

POSSIBILITIES FOR STRUCTURAL CONTROL:
The terrain offers no special difficulties for control by supporting structures. Since the avalanches are frequent, control measures should be studied immediately. Control by supporting structures in connection with snowdrift control and afforestation is the most economical procedure. Because of the proximity of Loveland Basin ski area and the chair lift, it would be a good test and study field.



Highway No. 6 --
Loveland Pass
Photo: May 11, 1962

FIVE CAR (L-7)

LOCATION:

Front Range; between the two legs of the second switchback on the west side of Loveland Pass on both sides of Pass Lake Creek.

STARTING SPOTS:

East slope between the two legs of the highway. The starting spots lie near timberline at an altitude of 11,600 feet m.s.l.; 2-1/2 acres (1 ha).

TRACK:

The moving snow travels only a short distance in a poorly defined path; average slope, 51 percent.

RUNOUT ZONE:

The track hits the highway without any transition zone.

AVALANCHES:

December 20, 1951: covered the highway and blocked traffic from 4:30 p.m. to 8:55 p.m.; caught five cars, two trucks; buried two men. January 7, 1957: covered highway for 250 feet to a depth of 10 feet. Has run to the road at least 14 times in the past 10 years.

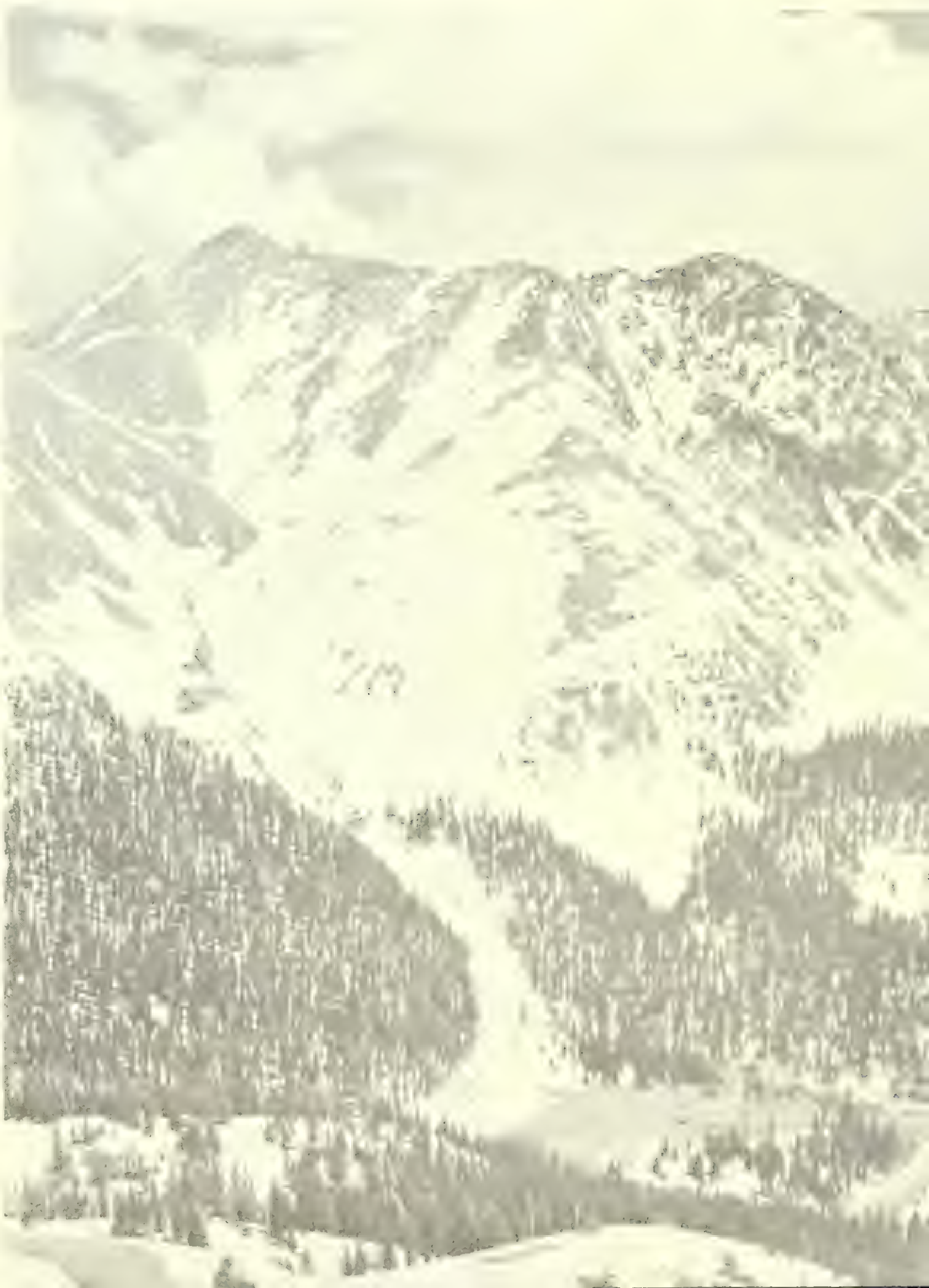
CLASSIFICATION:

Small-frequent.

POSSIBILITIES FOR STRUCTURAL CONTROL:

A spot highly qualified as a test field for supporting structures because the starting spots lie immediately below the highway, so there is no transportation problem. The area is easy to observe.

Highway No. 6 --
Loveland Pass
Photo: May 11, 1962



GRIZZLY (OR WEST PATROL) (L-8)

LOCATION:
Front Range; west face of Grizzly Peak.

CATCHMENT BASIN:
Big bowl shaped, west face of Grizzly Peak; above timberline; 13,400-12,000 feet m.s.l.; 110 acres (45 ha).

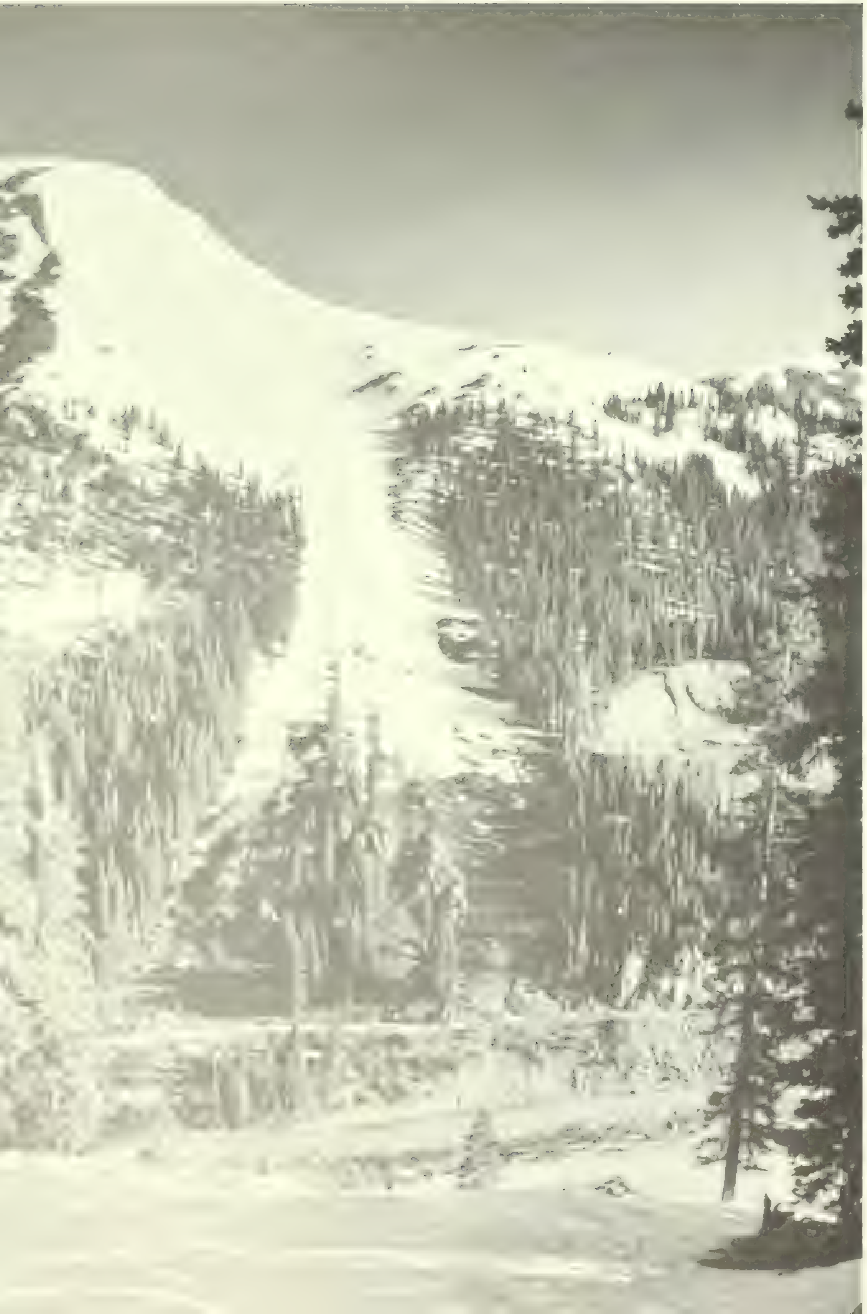
TRACK:
Narrow gulch; vertical drop, 2,200 feet; length, 4,800 feet; average slope, 46 percent. Upper half of track is very steep, 64 to 70 percent; lower half is more gentle with average slope of 32 percent. The gulch is curved, especially in the lower half, which is actually part of the runout zone since avalanches normally stop here.

RUNOUT ZONE:
In case of a large avalanche, the runout zone extends to the highway. This part of the runout zone is the alluvial fan of the gulch and the wide bottom of North Fork of Snake River. Length, 1,100 feet; width, 100 feet; average slope, 18 percent.

AVALANCHES:
This avalanche has not given trouble on the highway for a long time.

CLASSIFICATION:
Large-erratic.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Control is not urgent, but if it is desirable to protect the highway, terrain conditions are rather favorable for a diversion dam in the runout zone. Control in the starting zone is out of the question because it is too big and rugged.



Highway No. 6 --
Loveland Pass
Photo: May 11, 1962

LITTLE PROFESSOR (L-9)

LOCATION:

Front Range; southeast slope of summit point 12,293, northwest of Arapaho Basin ski area.

CATCHMENT BASIN:

Uniform southeast slope; above timberline; 12,100-11,600 feet m.s.l.; 7 acres (3 ha).

TRACK:

Wide opening in the timber of the slightly bowl-shaped slope; vertical drop, 1,260 feet; length, 2,700 feet; average slope, 47 percent. This avalanche has a tendency to spread out in the lower part; the width of the track is 800 feet near the highway.

RUNOUT ZONE:

No transition zone above the highway; avalanches reach the parking lot of Arapaho Basin ski area.

AVALANCHES:

December 30, 1951, covered the highway 5 feet deep. Has run to the road at least six times in past 10 years.

CLASSIFICATION:

Small-frequent.

POSSIBILITIES FOR STRUCTURAL CONTROL:

The terrain conditions are favorable for control in the starting zone. Because of the danger to the ski area parking lot, supporting structures in the starting zone are the only logical type of control. Since access to the starting zone is easy and very good observations can be taken from the opposite slope during the whole winter, this avalanche would be a good study field for supporting structures. Snow conditions in the starting zone may be difficult because heavy snowdrifts must be expected.

Highway No. 6 --
Loveland Pass
Photo: May 11, 1962

ASSOCIATED LITTLE PROFESSOR (OR CLIFF) (L-10)

LOCATION:
Front Range; south slope of summit point 12,293 northwest of Arapaho Basin; 1,000 feet west of the LITTLE PROFESSOR avalanche.

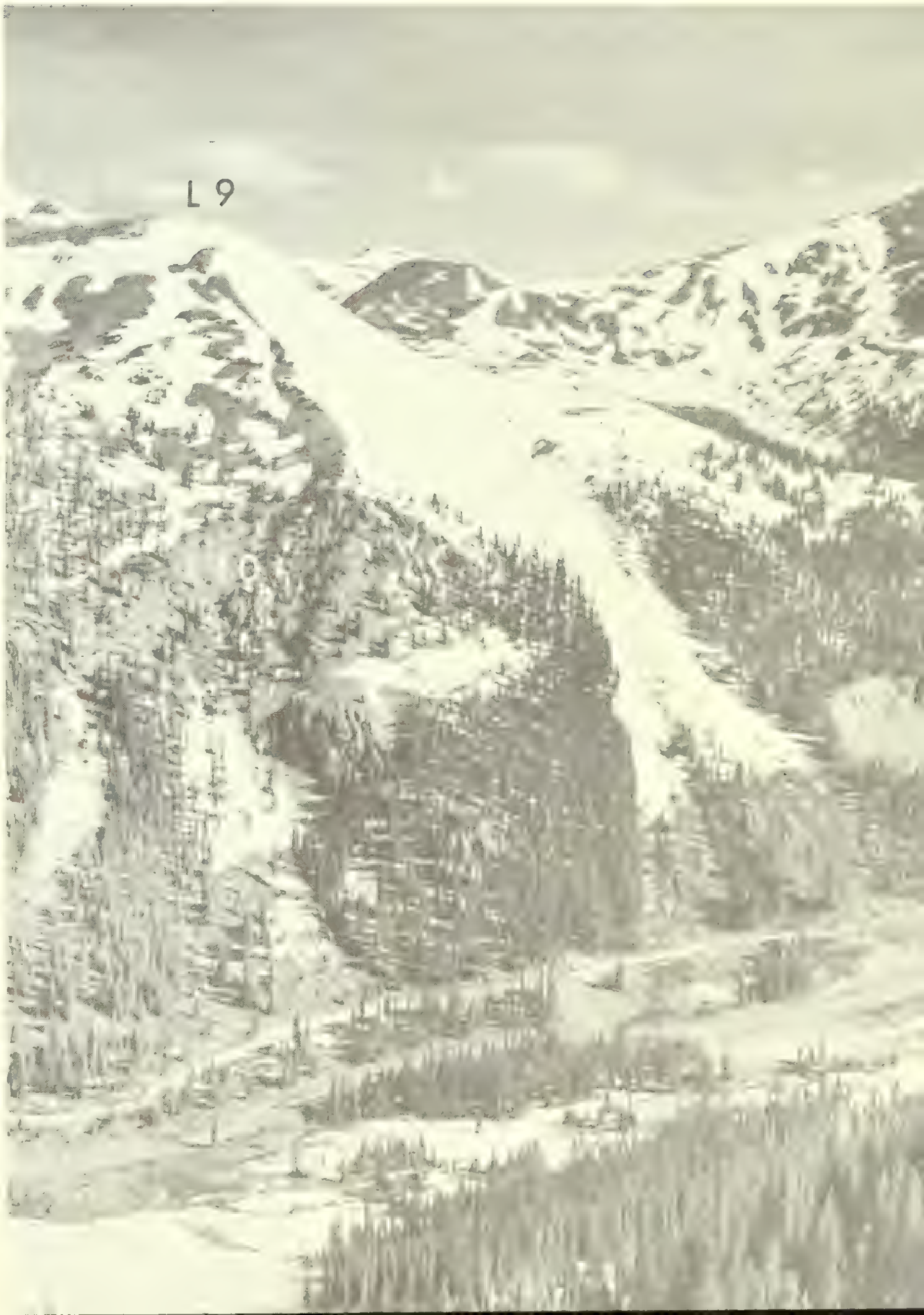
STARTING ZONE:
Funnel-shaped erosion surface below timberline; very few trees on the steep, rocky slope; 11,600-11,200 feet m.s.l.; 7 acres (3 ha).

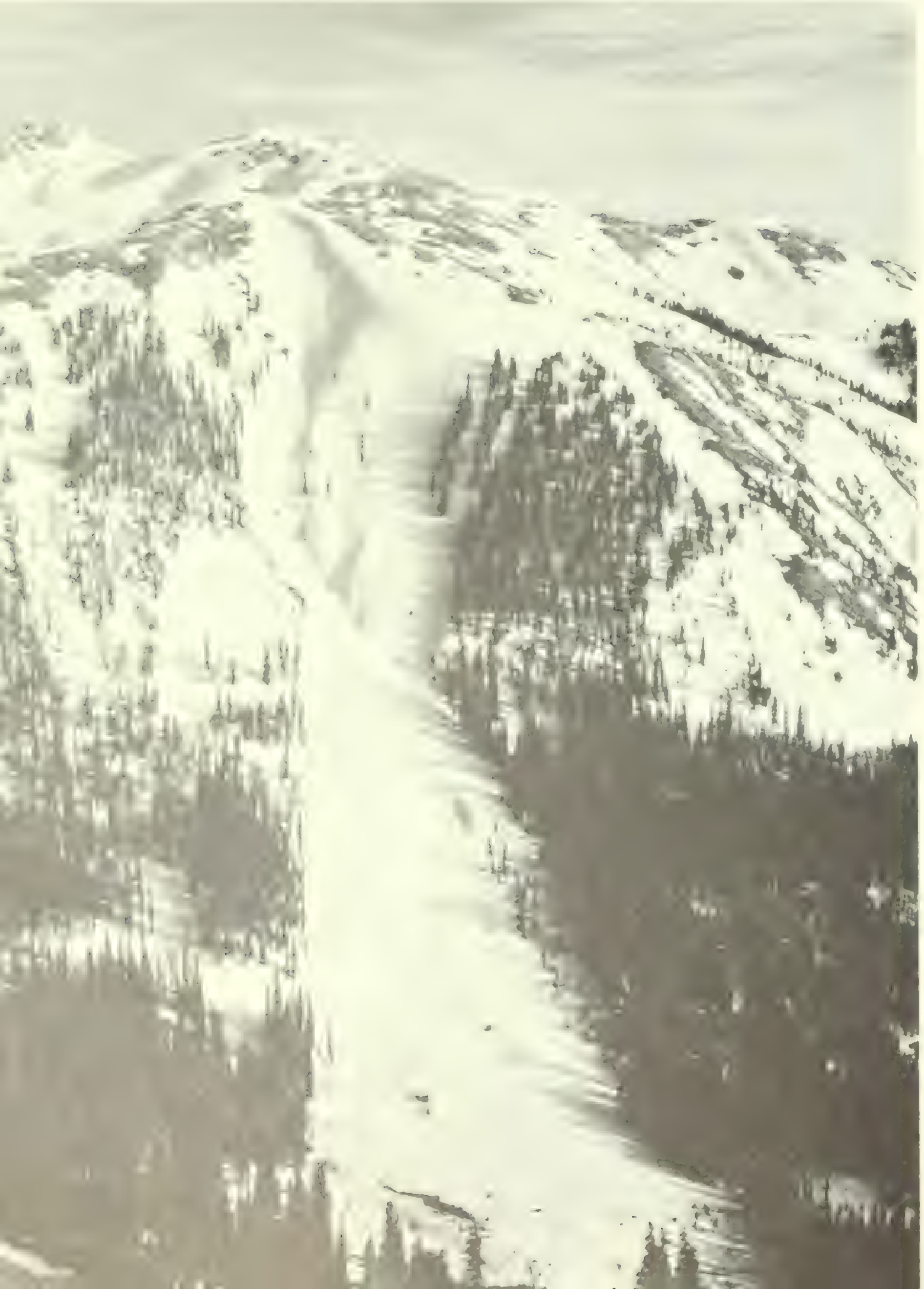
TRACK:
Opening in the woods; slightly bowl shaped; vertical drop, 800 feet; length, 1,300 feet; average slope, 62 percent; width, 200 feet.

RUNOUT ZONE:
No transition zone above highway; track hits highway directly.

CLASSIFICATION:
Small-occasional.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Since the starting zone shows a tendency to erode by rockfall, its stabilization should be studied. Except for the unstable ground and some very steep spots, there are no difficulties for control with supporting structures. Afforestation would be the most important control measure.





Highway No. 6 --
Loveland Pass
Photo: May 9, 1962

PALLAVICINI (L-11)

LOCATION:
Front Range; north slope of summit point 12,144 southwest of Arapaho Basin ski area.

CATCHMENT BASIN:
Bowl-shaped depression in the north-facing slope; above and below timberline; 12,000-11,200 feet m.s.l.; 15 acres (6 ha).

TRACK:
Wide opening in the heavily timbered slope; vertical drop, 1,280 feet; length, 2,700 feet; average slope, 47 percent.

RUNOUT ZONE:
Flat bottom of the Snake River Valley; under severe conditions the avalanche may run across the 500-foot-wide valley bottom and reach the highway on the opposite slope.

AVALANCHES:
The starting zone is controlled intensively by explosives and protective skiing because it lies within the Arapaho Basin ski area.

CLASSIFICATION:
Intensive skiing stabilizes the snowpack in the starting zone. Therefore, it is very unlikely that big snow masses will start. During prolonged and severe storms, however, when no skiing is possible, the snow masses may become big enough to form an avalanche that reaches the highway.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Terrain and vegetation conditions would be favorable for control by supporting structures; however, structural control is out of the question because of ski use of this avalanche track.

Highway No. 6 --
Loveland Pass
Photo: January 9, 1962

BLACK WIDOW (L-12)

LOCATION:
Front Range; south slope of summit point 12,293 northwest of Arapaho Basin ski area.

CATCHMENT BASIN:
Bowl-shaped depression in the slope above and below timberline; 12,100-11,500 feet m.s.l. Also a narrow and very steep opening in the timber to the west of the main avalanche. The two tracks join just before reaching the highway, 20 acres (8 ha).

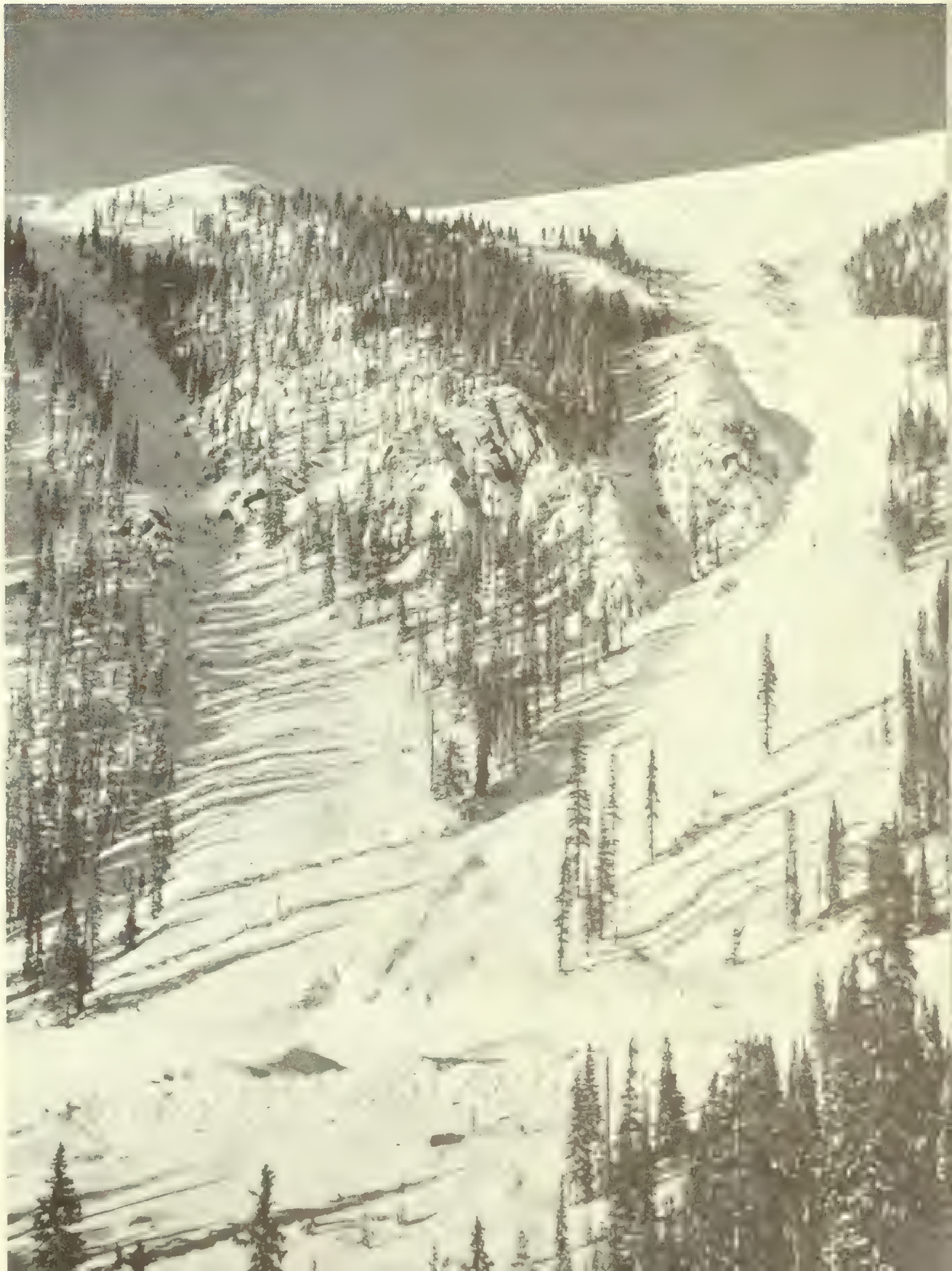
TRACK:
Main track--steep trough in the slope; wide in the upper part; narrow in the lower part. Vertical drop, 1,400 feet; length, 2,500 feet; average slope, 56 percent. Secondary track--steep slot in the timber; vertical drop, 920 feet; length, 1,500 feet; average slope, 61 percent.

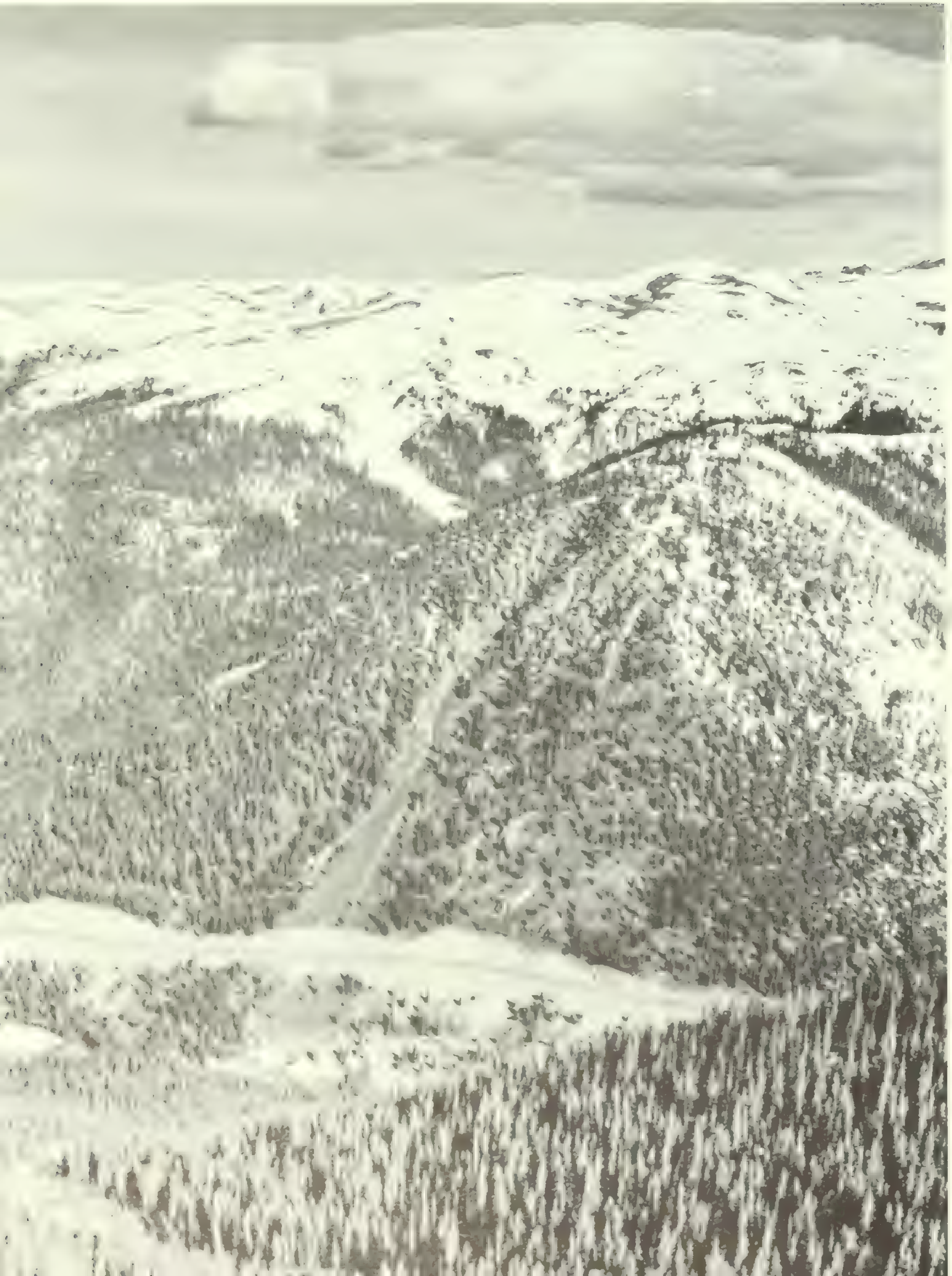
RUNOUT ZONE:
No transition zone above highway; track is 200 feet wide where it crosses highway; runout zone is below road in valley bottom.

AVALANCHES:
Ran on January 6, 1962. Has run to the road at least six times in past 10 years and usually brings debris to the highway.

CLASSIFICATION:
Medium-frequent.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Terrain conditions are favorable for control by supporting structures. Since this is a medium-size avalanche, an avalanche shed should also be considered. Some guide walls in the track would make a shorter shed possible.





Highway No. 6 --
Loveland Pass
Photo: May 11, 1962

HAPPY END (OF FINGER) (L-13)

LOCATION:

Front Range; southeast slope of a timbered ridge (11,820 feet), 1-1/2 miles west of Arapaho Basin ski area.

STARTING ZONE:

A very steep channel-like depression in the slope with a tendency for erosion. It is partly rocky and has scattered timber; 11,500-11,000 feet m.s.l.; 5 acres (2 ha).

TRACK:

Narrow opening or slot in the forest; vertical drop, 1,060 feet; length, 1,600 feet; average slope, 66 percent.

RUNOUT ZONE:

No transition zone above highway; track crosses highway and runout zone lies below road in valley bottom.

AVALANCHES:

Has run to the road at least twice in past 10 years.

CLASSIFICATION:

Small-occasional. In an average winter, only a little snow would be expected in this area.

POSSIBILITIES FOR STRUCTURAL CONTROL:

Since the starting zone shows a tendency to erode, mostly by rockfall, its stabilization should be studied. Other than some cliffs and very steep spots, there would be no difficulties for controlling it with supporting structures. Afforestation would be the most important control measure.

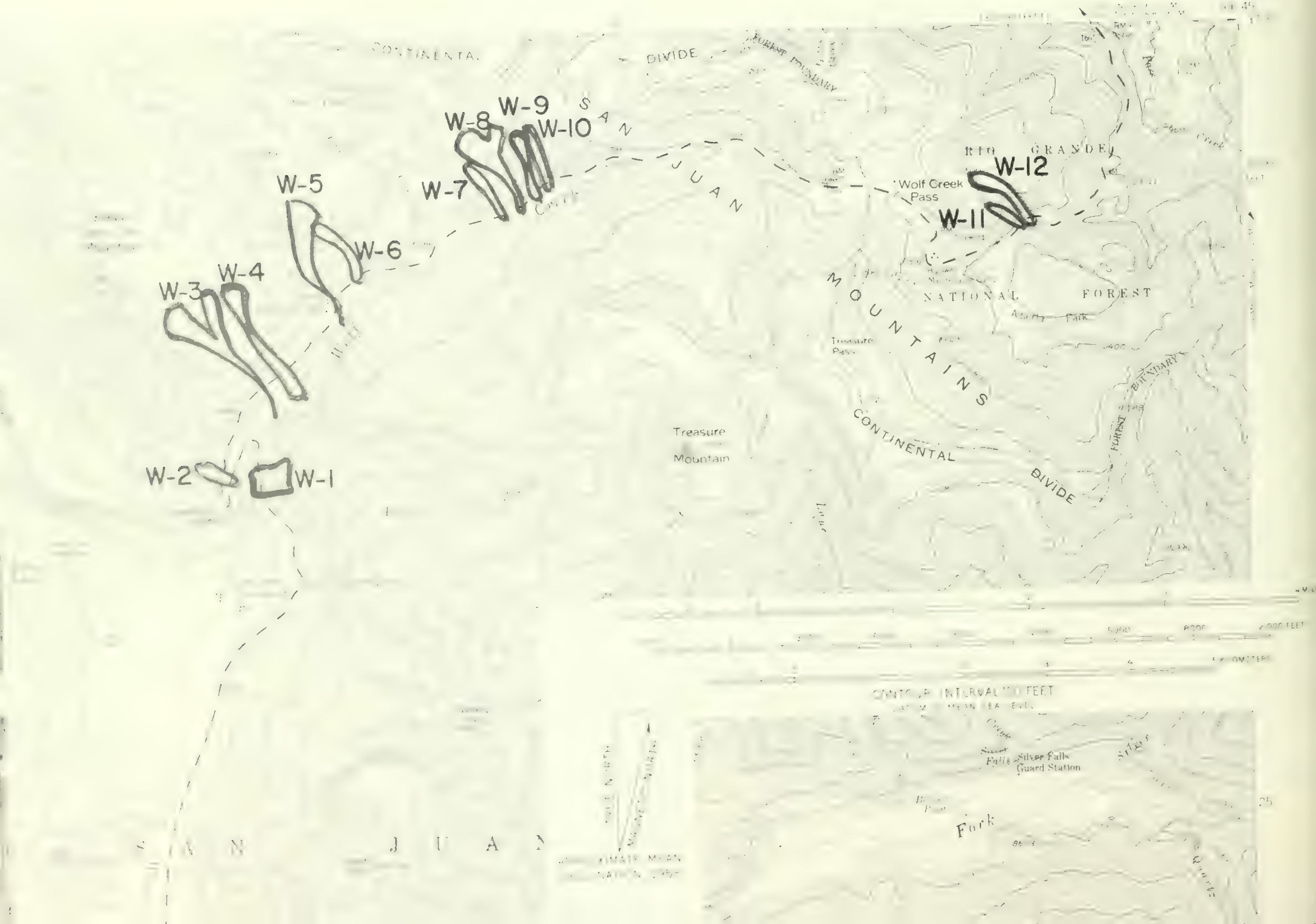
SUMMARY FOR HIGHWAY No. 160: WOLF CREEK PASS

The avalanches on Wolf Creek Pass can be easily classified into four very distinct and homogeneous groups:

Group 1: Albertas--ALBERTA, ALBERTA'S COUSIN
Group 2: Organ Pipes--STEPHEN, DANIEL, ANDREW, KATHY (160 EAST II, 160 EAST I, 160 WEST)
Group 3: Sheep Mountain--PIT, CAMP, SNOWFLAKE, BOULDER CREEK
Group 4: Afforestations--SWITCHBACK, PALISADES
The Coyotes or Cliffs are considered bankslides.

A general structural defense plan should start with the two easiest groups, the Albertas and the Afforestations. There is little question that control of the starting zone is the appropriate procedure for these two groups. Special precautions may be needed for the steep places in the PALISADES.

The Organ Pipes and Sheep Mountain groups have several features in common and the appropriate type of structural control is still in question. Access to the starting zone is often difficult and the possibility of help from afforestation is limited. The larger avalanches of these groups might be controlled by avalanche sheds while the small ones offer a better chance for supporting structures in the starting zones. More information and observations are needed before definite recommendations can be made.



CONTINENTAL DIVIDE
FOREST BOUNDARY
SAN JUAN MOUNTAINS
W-1
W-2
W-3
W-4
W-5
W-6
W-7
W-8
W-9
W-10
W-11
W-12
Wolf Creek Pass
RIO GRANDE NATIONAL FOREST
Alberta Park
Treasure Pass
Treasure Mountain
CONTINENTAL DIVIDE
FOREST BOUNDARY
CONTOUR INTERVAL FEET
Silver Falls Guard Station
Fork
SAN JUAN

Highway No. 160 --
Wolf Creek Pass
Photo: March 26, 1962

PALISADES (W-1)

LOCATION:
San Juan Mountains, Wolf Creek Pass west; west slope of Treasure Mountain.

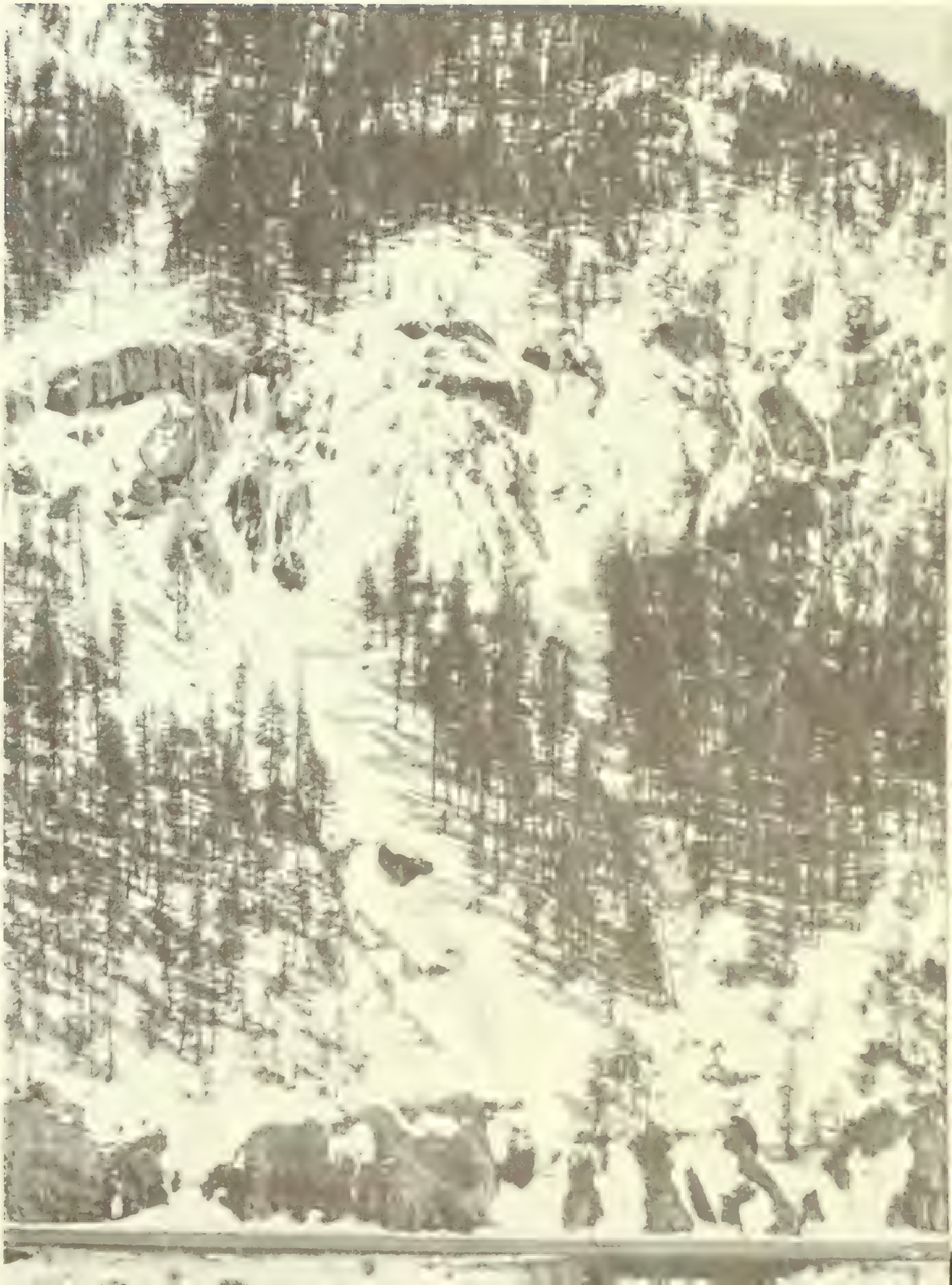
STARTING ZONE:
In steep cliffs just above the highway. On the cliffs are scattered trees; starting spots are indefinite, 9,200-8,400 feet m.s.l.; 7 acres (3 ha).

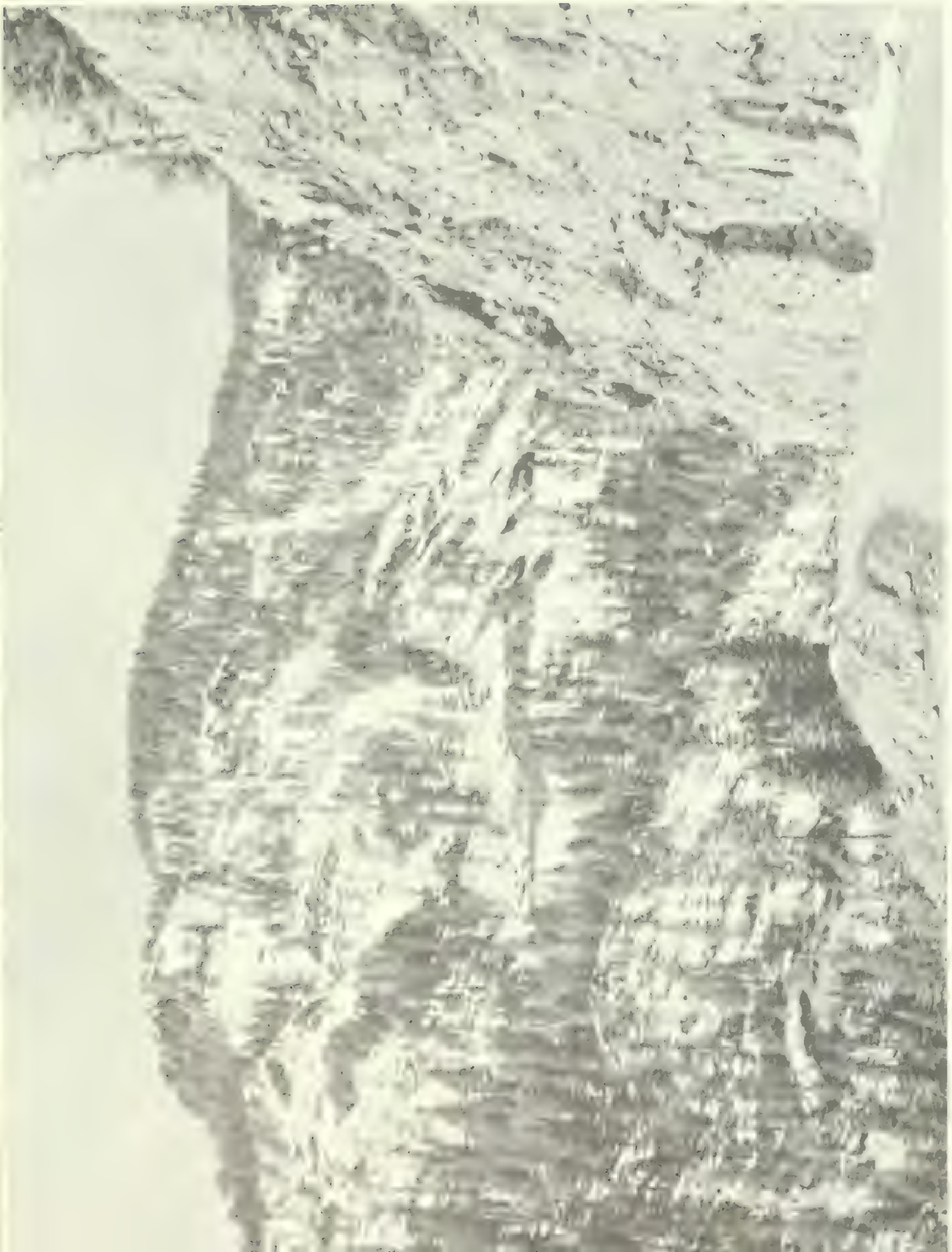
TRACKS:
Indefinite; the snow may fall from several spots and gullylike depressions in the cliffs; vertical drop, 800 feet; length, 1,200 feet; average slope, 67 percent. For a distance of 800 feet along the road avalanches hit the highway directly; the snow masses fall almost vertically into the road cut.

RUNOUT ZONE:
In the bed of Wolf Creek below the highway.

CLASSIFICATION:
Small-frequent.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Most obvious is the control of the starting zone by supporting structures. Because the cliffs will give considerable difficulties, the conditions must be studied further.





Highway No. 160 --
Wolf Creek Pass
Photo: March 26, 1962

SWITCHBACK (W-2)

LOCATION:
San Juan Mountains, Wolf Creek Pass west; southeast slope of Sheep Mountain.

STARTING ZONE:
In little cliffs and on steep spots of a generally timbered slope; 9,400-8,800 feet m.s.l.; 2 acres (1 ha).

TRACK:
Several slots in the timber, not confined; vertical drop, 600 feet; length, 900 feet; average slope, 67 percent; sliding snow masses may cross the switchback twice.

RUNOUT ZONE:
No transition zone above highway.

CLASSIFICATION:
Small-occasional.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Adequate control could definitely be obtained by means of supporting structures and afforestation.

Highway No. 160 --
Wolf Creek Pass
Photo: July 5, 1962

BOULDER CREEK (W-3)

LOCATION:
San Juan Mountains, Wolf Creek Pass west; southeast slope of Sheep Mountain.

CATCHMENT BASIN:
Two separate bowl-shaped basins on the south- and southeast-facing slopes of Boulder Creek; the basins are steep and somewhat cliffy; below timberline; 11,100-10,600 feet m.s.l.; 30 acres (12 ha).

TRACK:
Two tracks join at elevation of 10,000 feet m.s.l.; track of the south-facing basin, 2,200 feet; average slope, 51 percent. Southeast-facing track, 2,700 feet; average slope, 36 percent. Below 10,000 feet m.s.l.; common track follows gully of Boulder Creek: length, 2,000 feet; average slope, 45 percent. Usually, only avalanches of south-facing catchment basin run to highway; width of track near highway 200 feet.

RUNOUT ZONE:
Track is steep where it crosses highway; runout zone lies in gorge of Wolf Creek below highway.

CLASSIFICATION:
Medium-occasional.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Control in starting zones is technically possible, but uneconomical due to remoteness and extent of catchment basins. Mouth of Boulder Creek is bad spot because of rockfalls; an avalanche shed would be best, and would help eliminate bankslides of earth and boulders.

SNOWFLAKE (OR BIG) (W-4)

LOCATION:
San Juan Mountains, Wolf Creek Pass west; southeast slope of Sheep Mountain.

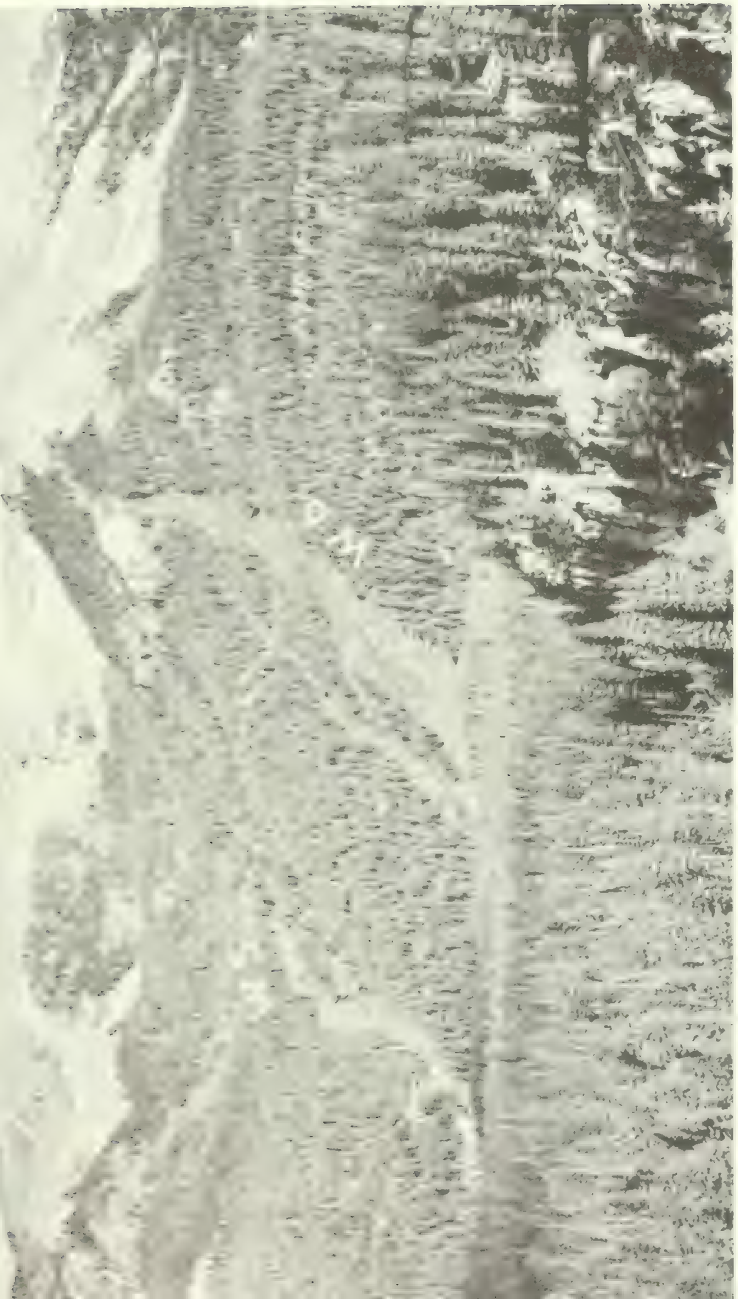
CATCHMENT BASIN:
Bowl-shaped depression on ridge; some cliffs; below timberline; 11,100-10,400 feet m.s.l.; 15 acres (6 ha).

TRACK:
Gullylike depression in slope; vertical drop, 1,900 feet; length, 4,000 feet; average slope, 48 percent; width of track near highway, 500 feet.

RUNOUT ZONE:
No transition zone above highway; crosses highway and runs down to gorge of Wolf Creek.

CLASSIFICATION:
Medium-occasional.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Control of starting zone, including afforestation, is most obvious.



Highway No. 160 --
Wolf Creek Pass
Photo: July 5, 1962

CAMP (W-5)

LOCATION:
San Juan Mountains, Wolf Creek Pass west.

STARTING ZONE:
Grooved and rugged south slope of ridge between Camp Creek and Lake Creek; below timberline; 11,400-10,600 feet m.s.l.; steep slope shows some cliffs and has scattered timber; 10 acres (4 ha).

TRACK:
Two distinct parts; upper two-thirds of length follows two depressions in slope; vertical drop, 1,440 feet; length, 2,300 feet; average slope, 63 percent; at lower end of this first section, the avalanche turns a right angle to left and follows for 1,500 feet the gully of Camp Creek at an average slope of only 30 percent.

RUNOUT ZONE:
Only under exceptionally severe conditions would the avalanche run down the second section in the narrow gully and reach the highway. Normally, avalanches stop at foot of steep first section of track.

CLASSIFICATION:
Medium-erratic.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Starting zone lies entirely in timber; control here is unlikely because of ruggedness and size. Diversion dams or catching dams might be possible in lower part of track. A more detailed examination is necessary.

PIT (W-6)

LOCATION:
San Juan Mountains, Wolf Creek Pass west; south slope of ridge between Camp Creek and Lake Creek.

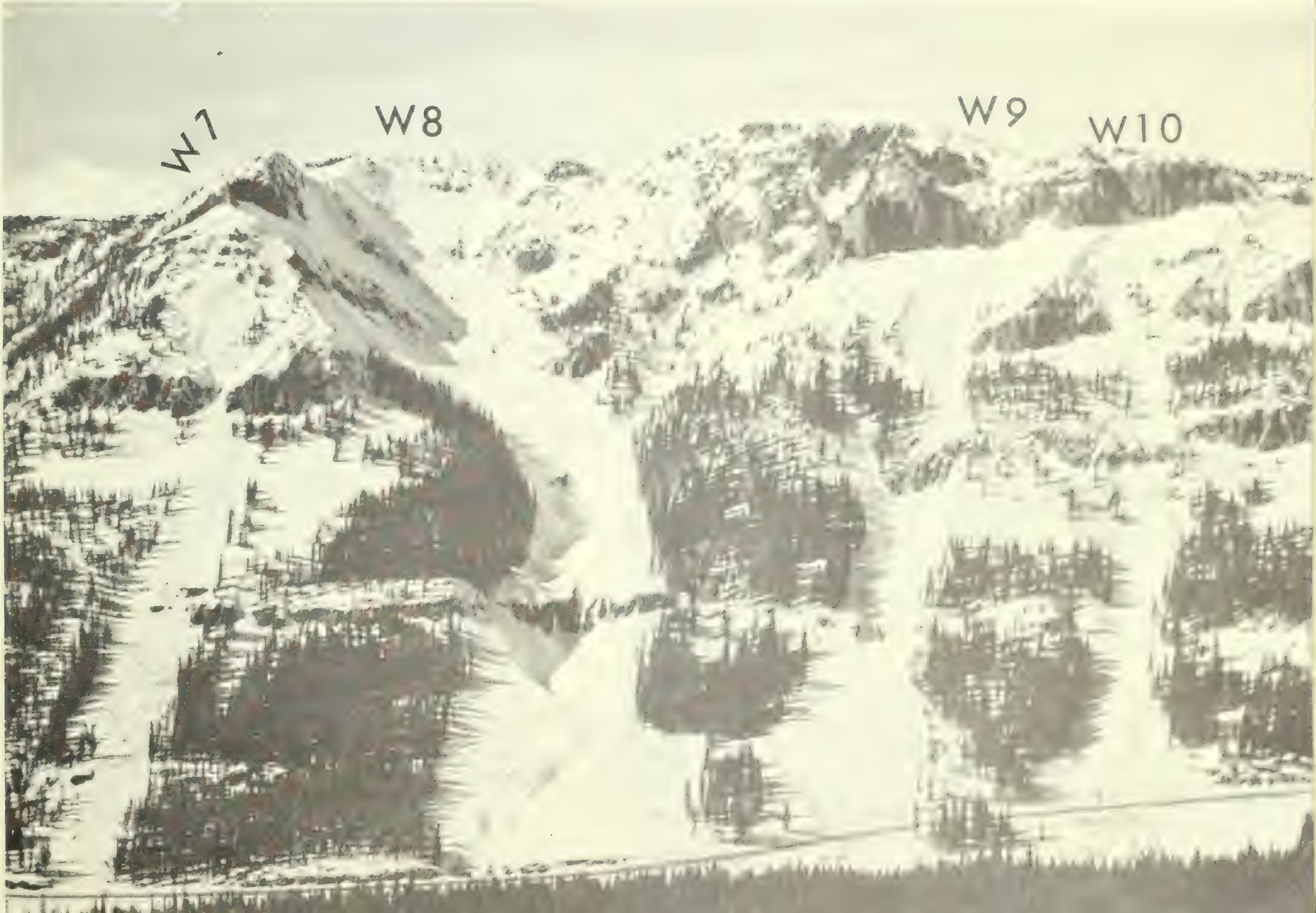
STARTING ZONE:
Depression in ridge; 11,200-10,800 feet m.s.l.; below timberline; 2 acres (1 ha).

TRACK:
Slot in timbered slope; steep track comes down to highway and hits it full speed. Vertical drop, 1,720 feet; length, 3,200 feet; average slope, 54 percent. Track shows a gentle middle section, but is very steep where it crosses road. Width of track near highway, 500 feet.

AVALANCHES:
Two trucks were knocked off road in winter of 1957-58; slide is hard to control with artillery.

CLASSIFICATION:
Small-occasional.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Control of starting zone is probably most economical control measure. Since whole track lies on timbered slope, afforestation would be an integral part of project.


W7
W8
W9
W10

Highway No. 160 --
Wolf Creek Pass
Photo: March 26, 1962

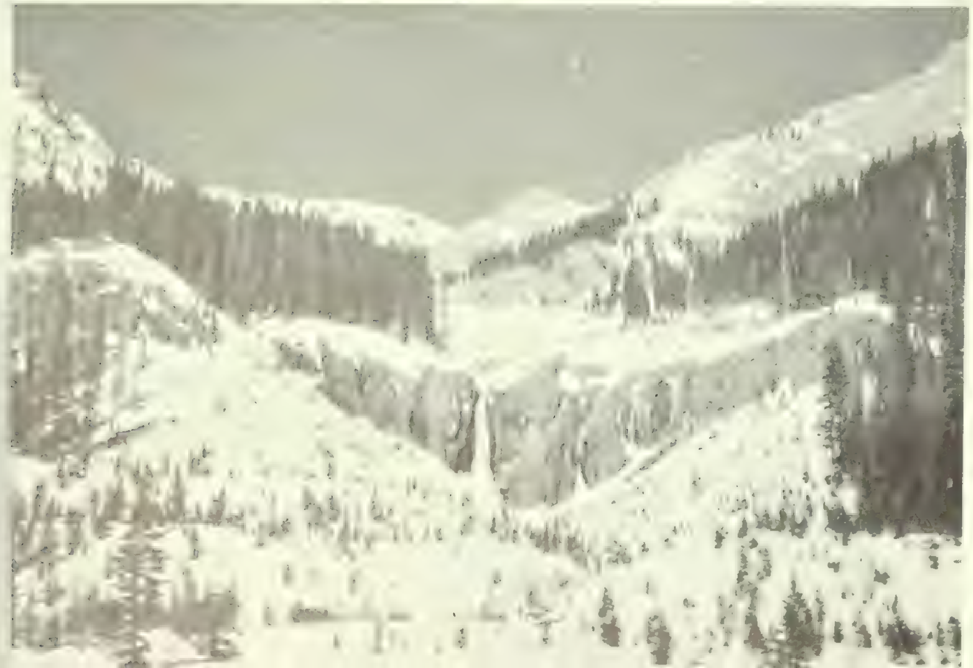
(ORGAN PIPE GROUP)

KATHY (OR 160 WEST) (W-7)

LOCATION:
San Juan Mountains, Wolf Creek Pass west; south slope.

CATCHMENT BASIN:
Depression in ridge forming left shoulder of Lake Valley; below timberline; 11,200-10,600 feet m.s.l.; 7 acres (3 ha).

TRACK:
Steep slope, track falls over cliffs twice; vertical drop, 1,300 feet; length, 2,300 feet; average slope, 56 percent. Track crosses highway without transition zone; width of track, 130 feet.



RUNOUT ZONE:
Valley bottom of Wolf Creek below the highway.

CLASSIFICATION:
Small-occasional.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Control of starting zone by supporting structures and afforestation seems most promising.

ANDREW (OR 160) (W-8)

LOCATION:
San Juan Mountains, Wolf Creek Pass west; south slope.

CATCHMENT BASIN:
A large cirque with steep rims above timberline; 11,600-10,800 feet m.s.l.; 37 acres (15 ha).

TRACK:
A gully with irregular slope; terraces alternate with cliffs; vertical drop, 1,670 feet; length, 4,000 feet; average slope, 42 percent.

RUNOUT ZONE:
Alluvial fan of the gully; length (above highway) 1,200 feet; average slope, 30 percent; width of runout zone, 300 feet. Below highway, avalanche crosses to valley bottom of Wolf Creek.

CLASSIFICATION:
Large-occasional.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Because of extent of catchment basin, it is unlikely that control of starting zone is economical. Runout zone above highway is too steep to use retarding or catchment structures. The bedrock, a ledge near the highway, is favorable for construction of an avalanche shed.

DANIEL (OR 160 EAST I) (W-9)

LOCATION:
San Juan Mountains, Wolf Creek Pass west; south slope.

CATCHMENT BASIN:
Holes in a band of cliffs and depressions in steep slope. Above and below timberline; 11,600-10,400 feet m.s.l.; 10 acres (4 ha). Starting spots are indefinite.

TRACK:
Irregular, steep, and rocky slope; steep cliffs alternate with flat terraces; vertical drop, 1,600 feet; length, 2,500 feet; average slope, 64 percent. Track is 250 feet wide where it crosses highway.

RUNOUT ZONE:
Above highway is a slight transition zone. Track has an average slope of 40 percent for a length of about 500 feet. Runout zone extends to valley bottom of Wolf Creek below highway.

CLASSIFICATION:
Medium-occasional.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Ruggedness of terrain is unfavorable for control of starting zone; starting zone not well defined; further studies needed for economical control.

STEPHEN (OR 160 EAST II) (W-10)

LOCATION:
San Juan Mountains, Wolf Creek Pass west; south slope.

CATCHMENT BASIN:
Depressions in cliffs and several steep slopes; 11,600-10,400 feet m.s.l.; above and below timberline; 5 acres (2 ha); starting spots are indefinite.

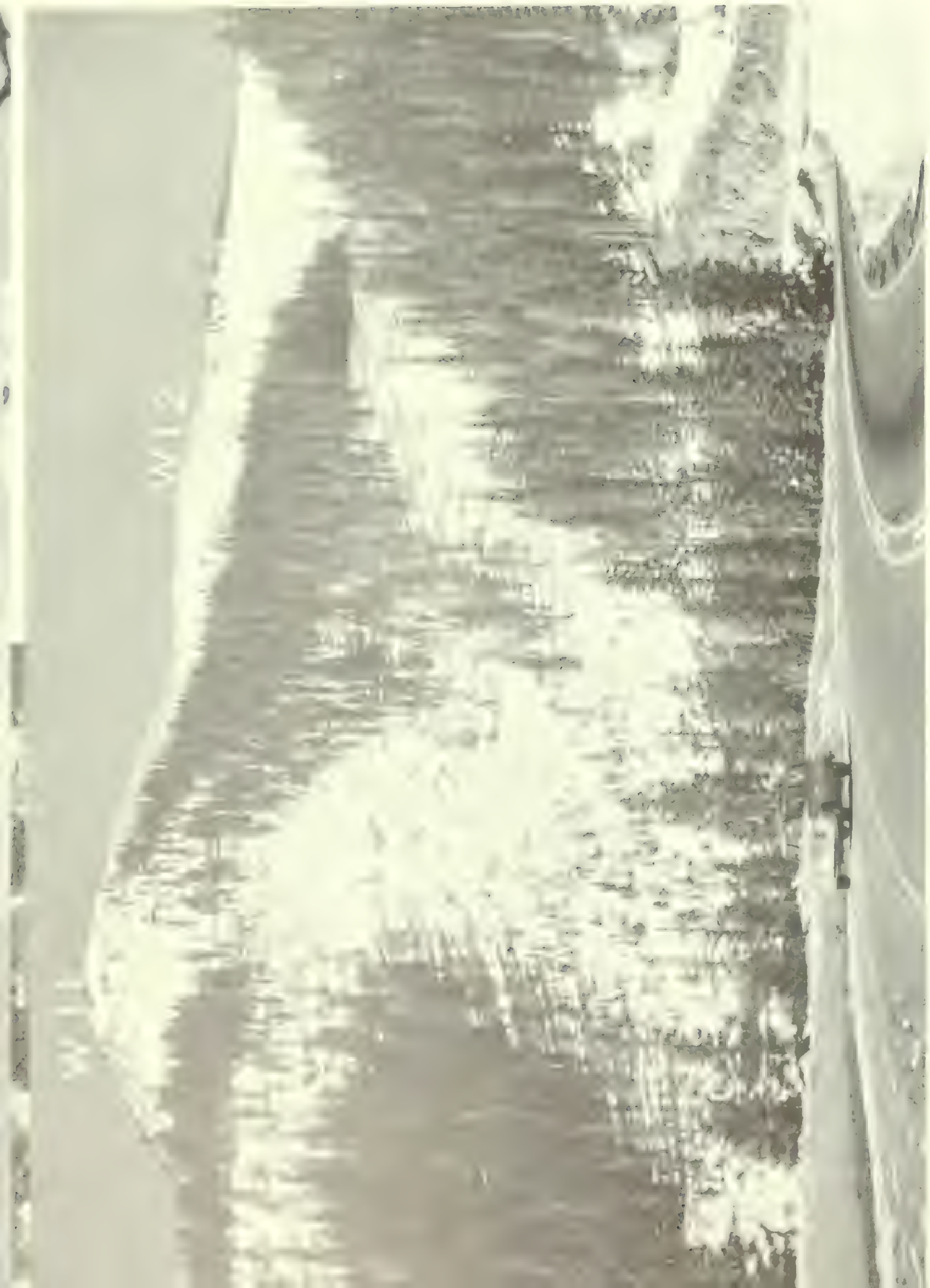
TRACK:
Irregular, steep, and rocky slope; steep cliffs alternate with flat terraces; vertical drop, 1,600 feet; length, 2,500 feet; average slope 64 percent. Track is 200 feet wide where it crosses highway.

RUNOUT ZONE:
Runout zone lies mainly below highway in flat valley bottom of Wolf Creek. There is only a slight decrease in slope of track above road.

CLASSIFICATION:
Small-occasional.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Control of starting zone may be difficult because the starting spots are rugged and indefinite. Since it is only a small avalanche, the possibilities of controlling the starting zone should be studied in more detail.

STEPHEN →



Highway No. 160 --
Wolf Creek Pass
Photo: January 5, 1962

ALBERTA (W-11)

LOCATION:
San Juan Mountains, Wolf Creek Pass east; southeast slope of Thunder Mountain.

STARTING ZONE:
Southeast-facing ridge; 11,200-10,900 feet m.s.l.; below timberline; 2 acres (1 ha).

TRACK:
Wide slot in timber; a slight depression in slope; path is covered with thick stand of young trees; rocks and boulders in upper part; vertical drop, 900 feet; length, 1,600 feet; average slope, 56 percent.

RUNOUT ZONE:
Track crosses highway; runout zone is below highway in gully of Pass Creek.

CLASSIFICATION:
Small-occasional.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Starting zone can be controlled with supporting structures. No technical difficulties; forest will later replace almost all structures.

ALBERTA'S COUSIN (W-12)

LOCATION:
San Juan Mountains, Wolf Creek Pass east; east slope of Thunder Mountain.

CATCHMENT BASIN:
Below crest of north-south ridge of Thunder Mountains; top just at timberline; bigger part below timberline; 11,400-11,000 feet m.s.l.; 10 acres (4 ha).

TRACK:
A curved gully; vertical drop, 1,040 feet; length, 2,800 feet; average slope, 37 percent.

RUNOUT ZONE:
Flat middle section reduces average slope to 37 percent. Many avalanches do not pass middle section. Thus, for small avalanches, middle track is runout zone. Large avalanches cross highway and run down to Pass Creek Gully.

CLASSIFICATION:
Medium-occasional.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Terrain is favorable for supporting structures. Some trouble would be caused by excessive snowdrift from gentle west slope of Thunder Mountain into catchment basin. Studies initiated with drift defenses (snow fences) should be continued.

SUMMARY FOR HIGHWAY No. 550: COAL BANK HILL AND MOLAS DIVIDE

Of the 13 avalanches listed by the Colorado Highway Department for this section of Highway 550, the West and East Lime Creek are considered bankslides, and the HENRY BROWN and SWAMP belong together; therefore, our list contains only 10 avalanches. There are four groups of avalanches:

Group 1: ENGINEER
Group 2: COAL CREEK, HENRY BROWN, SWAMP, SPRINGS
Group 3: KINO MINE
Group 4: Champion group--DEADWOOD, CHAMPION, PEACOCK, JENNIE PARKER, GLADSTONES

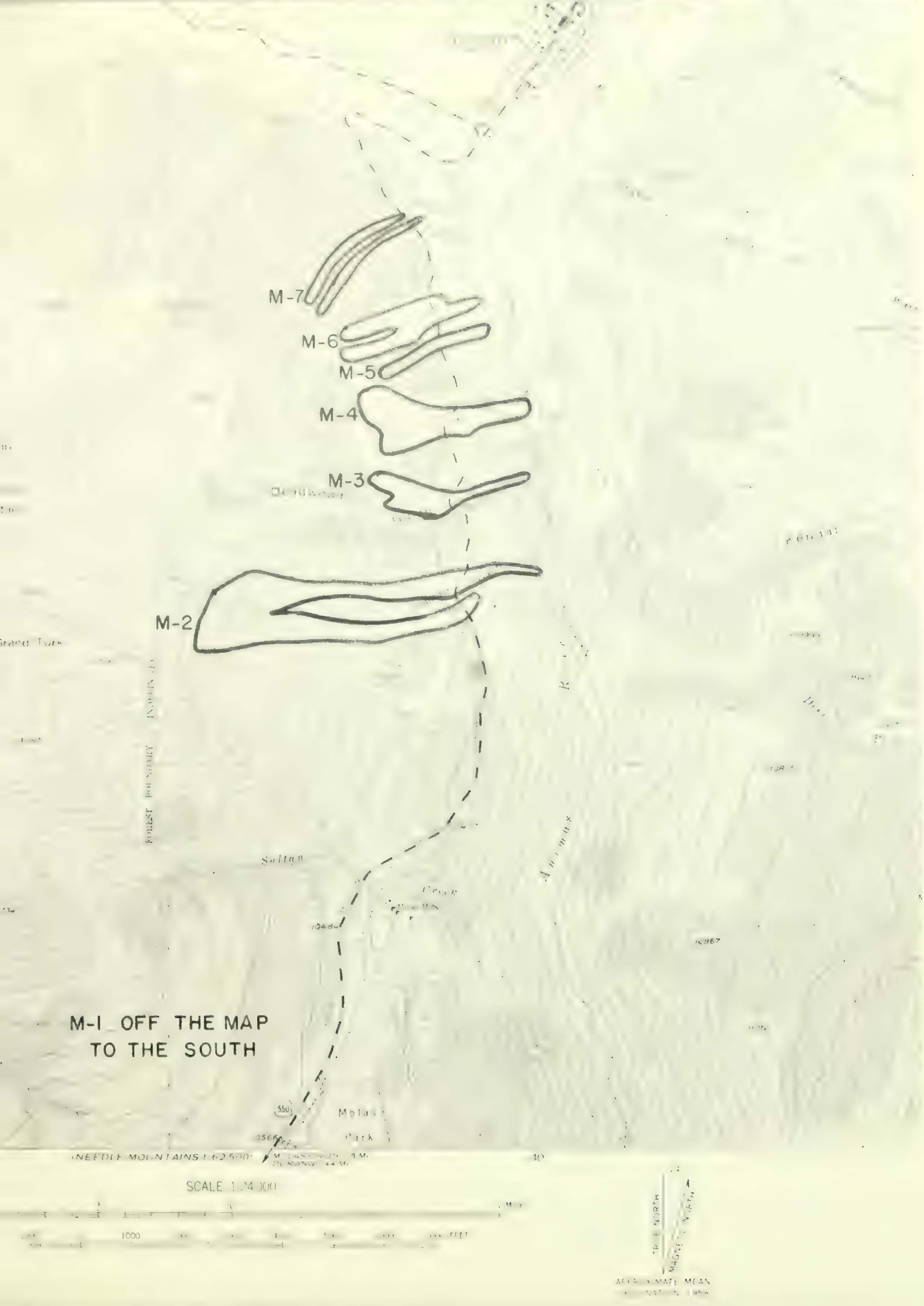
All these avalanches can be controlled by either supporting structures in the starting zone plus afforestation, or by diverting or catchment structures in the runout zone.

Group 2 (COAL CREEK, HENRY BROWN, SWAMP, and SPRINGS), and most of the Champion group, can be controlled by supporting structures and afforestations. CHAMPION and JENNIE PARKER may present some difficulties.

Although ENGINEER can also be controlled fairly well by supporting structures in the starting zone, it offers very little threat to the highway, and a diversion structure might be less expensive.

The large catchment basin above KINO MINE means supporting structures would be expensive. Avalanches might therefore be controlled by diversion and/or catchment structures, or, if detailed studies show that this would not be safe enough, by an avalanche shed in combination with guide dams.

There is no good modern topographic map for the area south of Molas Park. Therefore, map designations start with the Molas Divide group of avalanches. Map designation M-1 would be SPRINGS (or WATERFALL) avalanche; it is off the available map.


M-7
M-6
M-5
M-4
M-3
M-2
M-I OFF THE MAP
TO THE SOUTH
Sultan
Creek
Molas
Park
10484
10967
550
Animas
FOREST BOUNDARY
NEEDLE MOUNTAINS 1:62 500
SCALE 1:24 000
1000
FEET
TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN

Highway No. 550 --
Coal Bank Hill
Photo: July 4, 1962

ENGINEER (C-1)

LOCATION:
San Juan Mountains, near top of Coal Bank Hill; east-facing cliff and east slope on the east shoulder of Engineer Mountain, 600 feet north of highest point (Benchmark 10,664) of Coal Bank Hill.

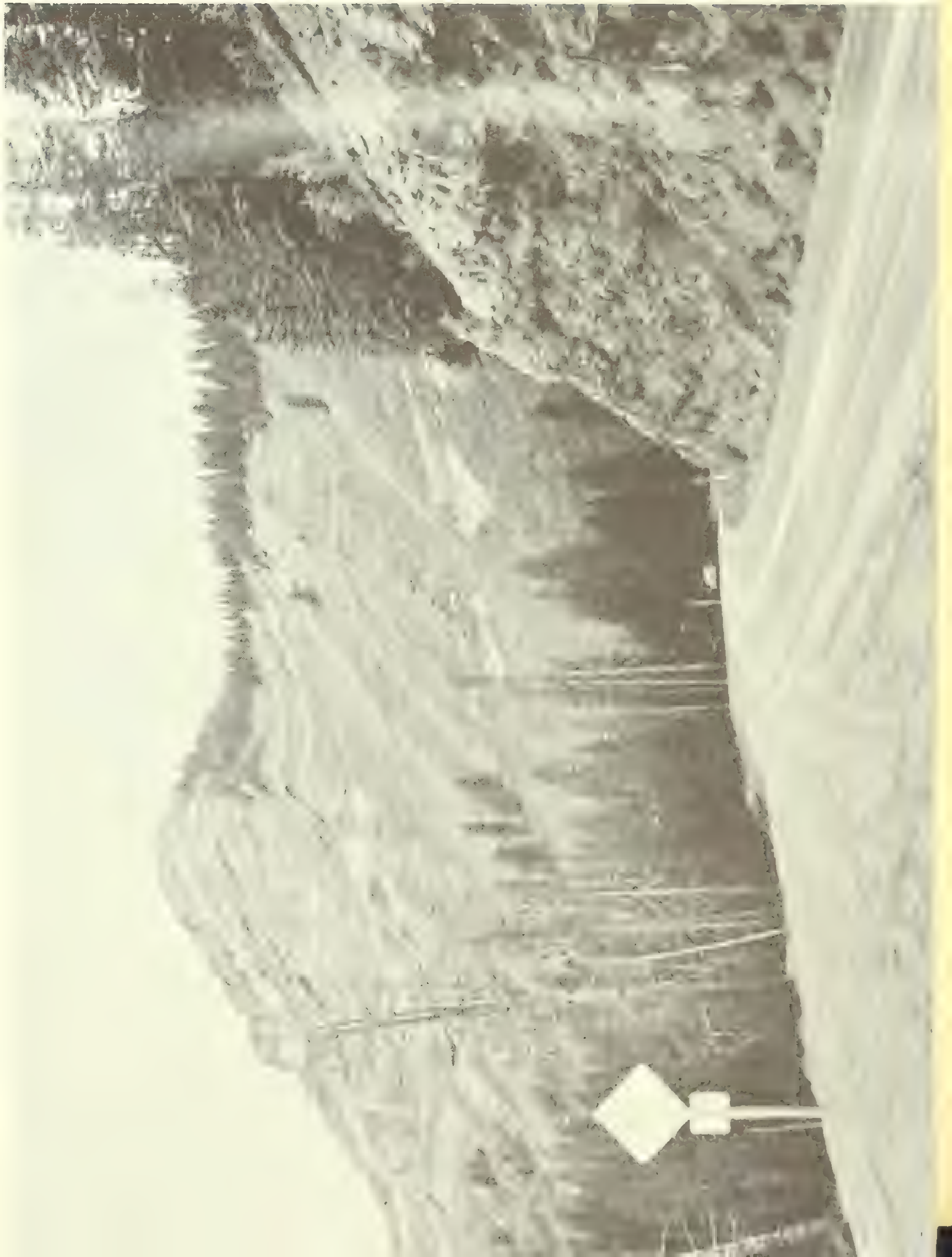
CATCHMENT BASIN:
Cliffs and steep but short slope; below timberline; 11,700-11,200 feet m.s.l.; 2-1/2 acres (1 ha).

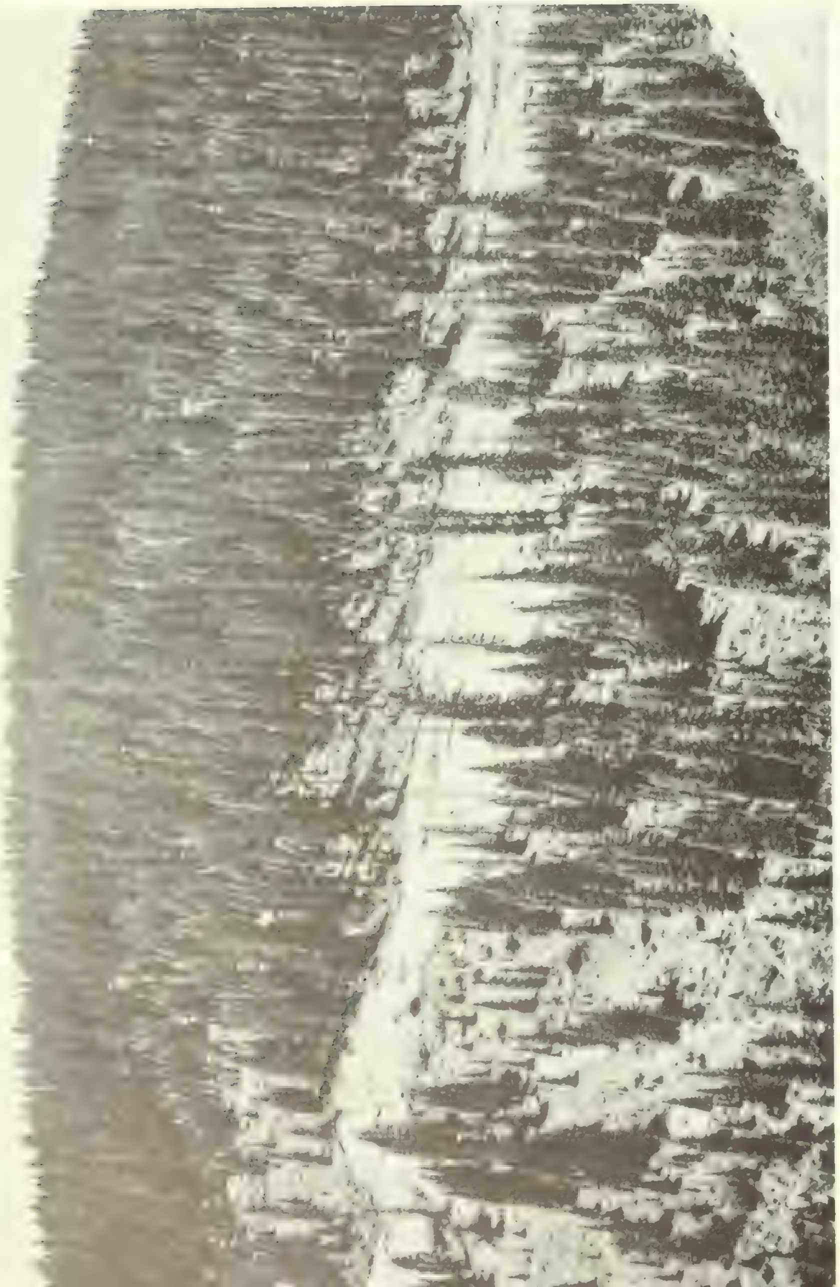
TRACK:
Grooved, steep slope with numerous small cliffs; no definite track; the entire slope may run.

RUNOUT ZONE:
Lower half of slope becomes more gentle, and near highway is nearly flat.

CLASSIFICATION:
Small-frequent. Only in exceptional cases does it reach the highway, however.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Forest on slope was probably cleared off by avalanche. Supporting structures would be possible. Since track is short avalanches do not reach high speeds. A catchment dam in the flat runout zone would also be possible.





Highway No. 550 --
Coal Bank Hill
Photo: July 4, 1962

COAL CREEK (C-2)

LOCATION:
San Juan Mountains: east side of Coal Bank Hill. Northeast-facing scarp of Coal Creek coming down from Engineer Mountain.

STARTING ZONE:
Slides start in light to moderately thick timber on the northeast-facing slope; 10,500-10,300 feet m.s.l.; 1 acre (1/2 ha).

TRACK:
Not confined; avalanches slide through small openings in timber. Vertical drop, 300 feet; length, 500 feet; average slope, 60 percent.

RUNOUT ZONE:
No runout zone above highway; avalanches come down through timber and hit highway directly.

CLASSIFICATION:
Small-erratic.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Very easy to control by supporting structures; integral part of defense works would be afforestation of openings in timber.

Highway No. 550 --
Coal Bank Hill
Photo: July 4, 1962

HENRY BROWN (C-3)
SWAMP (C-4)

LOCATION:
San Juan Mountains; east side of Coal Bank Hill; southeast slope of the smooth ridge between Coal Creek and Lime Creek.

STARTING ZONES:
Scarps of the ridge; 10,700-10,300 feet m.s.l.; 2-1/2 acres (1 ha).

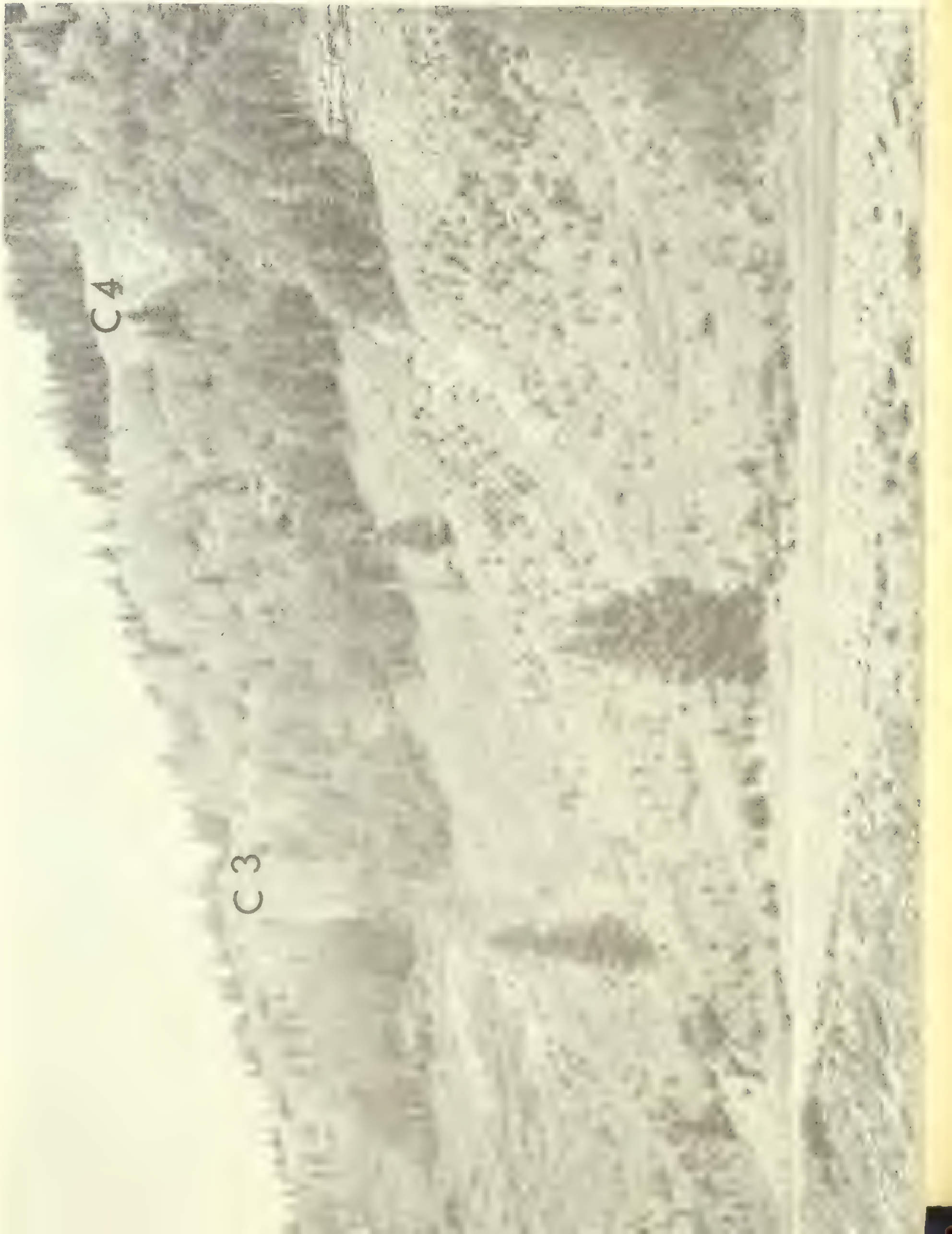
TRACKS:
Two gullylike depressions on slope; upper parts of tracks are steep, becoming more and more gentle in lower parts.

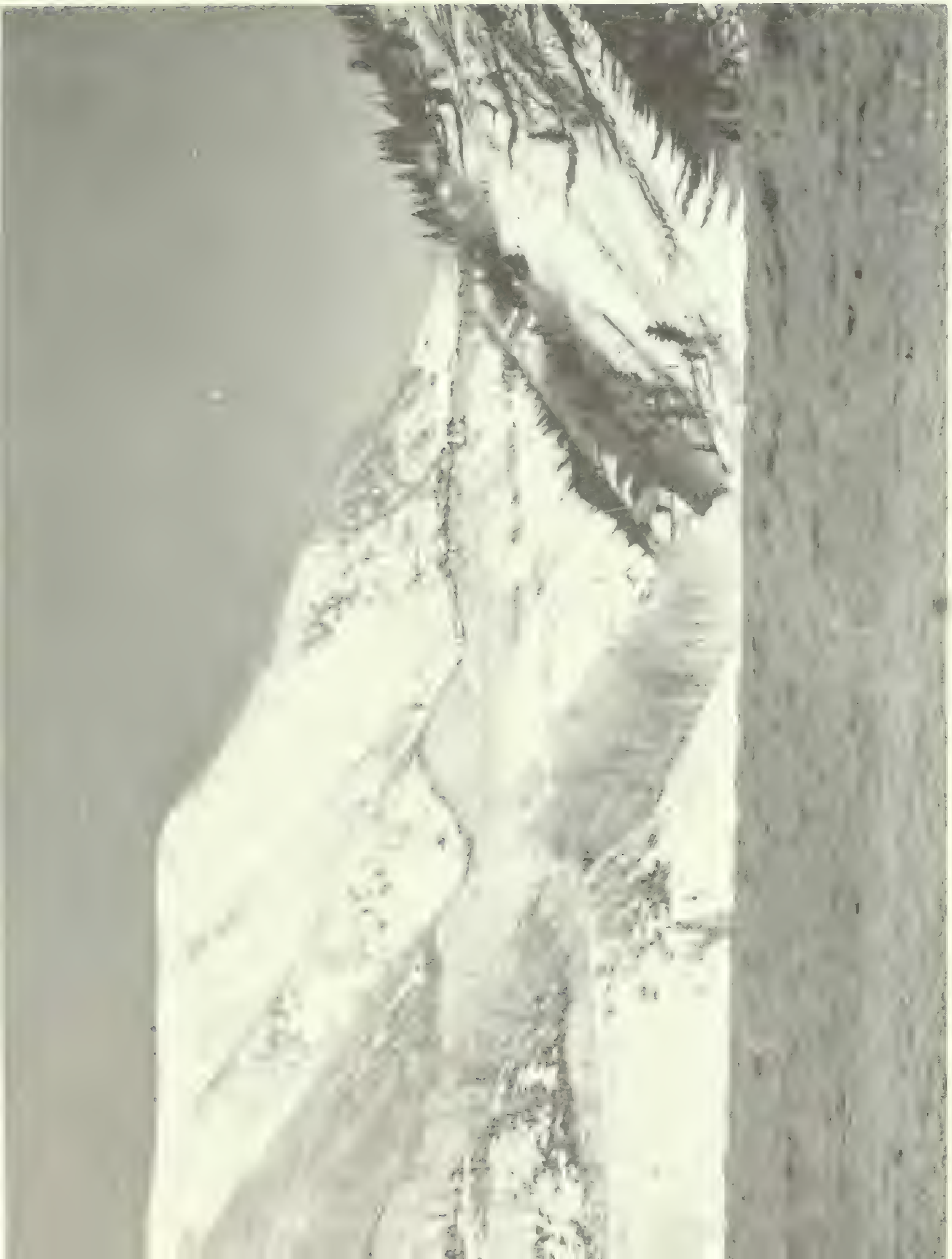
RUNOUT ZONE:
Smaller slides usually do not reach highway. Big snow masses, however, cross the road.

AVALANCHES:
HENRY BROWN is named after a man who was knocked off the road by a slide. SWAMP slide is just north of HENRY BROWN. Both slides have trees planted on both sides of the track but not in it.

CLASSIFICATION:
Small-frequent.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Control is principally a matter of afforestation. On steep slopes, supporting structures would help to protect both the highway and the young trees.





Highway No. 550 --
Molas Divide
Photo: January 3, 1962

SPRINGS (OR WATERFALLS) (M-1)

LOCATION:
San Juan Mountains, Molas Divide south; southwest-facing scarp of Lime Creek.

STARTING ZONE:
Three short gullies running down from the flat plateau to a little tributary to Lime Creek; 10,700-10,400 feet m.s.l.; 5 acres (2 ha).

TRACKS:
Vertical drop, 500 feet; length, 700 feet; average slope, 70 percent. Tracks hit highway directly, without a transition zone.

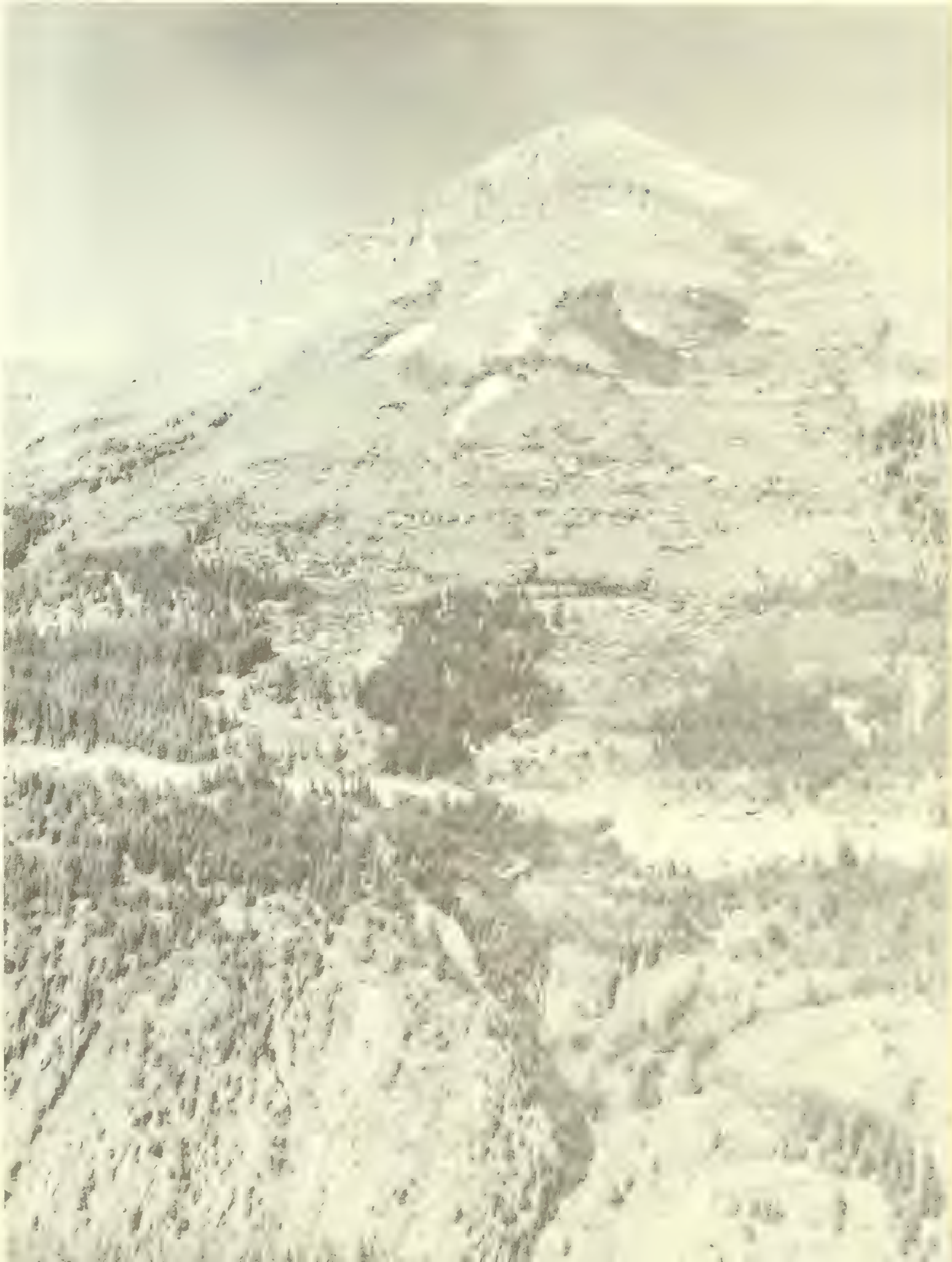
RUNOUT ZONE:
Tracks cross highway, and snow masses run to bottom of creek.

AVALANCHES:
Run during storms; after a storm, snow settles fast and stabilizes quickly.

CLASSIFICATION:
Small-frequent.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Control would be principally a matter of afforestation of the steep bank; supporting structures would help to protect both the highway and the plantation of trees.

Highway No. 550 --
Molas Divide
Photo: July 4, 1968



KINO MINE (M-2)

LOCATION:
North and south of Cataract Gulch, San Juan Mountains; Molas Divide north; east slope of Grand Turk.

CATCHMENT BASIN:
Wide, irregular east slope; above timberline; 13,000-11,400 feet m.s.l.; 60 acres (25 ha).

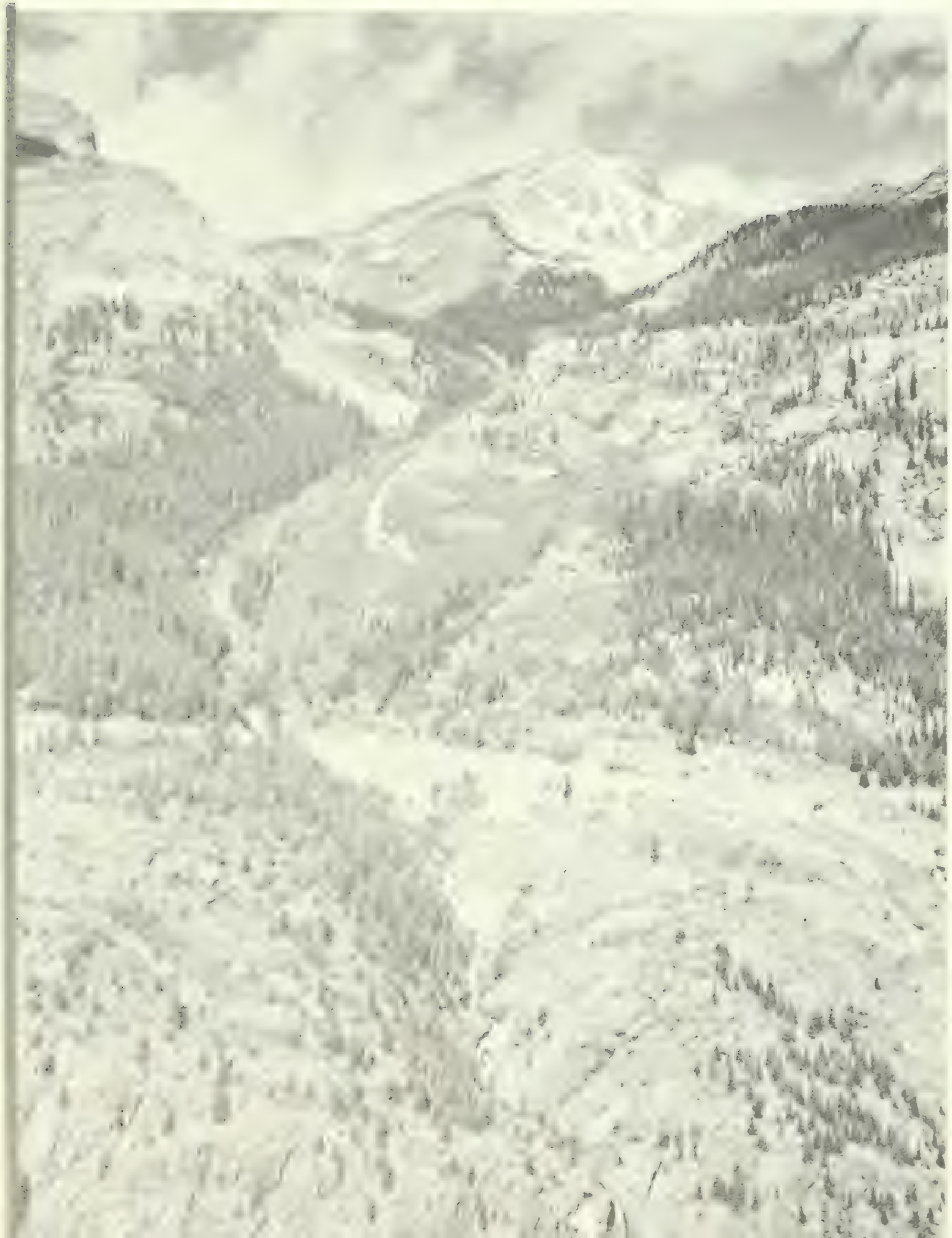
TRACK:
Irregular slope; vertical drop, 2,400 feet; length, 3,400 feet; average slope, 70 percent. End of track is indefinite: slow-moving snow masses stop on flat between highway and contour line 10,600 feet m.s.l.; fast-moving snow masses cross flat section and highway. Upper part of track is ill defined, laterally. Just above highway, two usual paths can be distinguished: Cataract South and Cataract North.

RUNOUT ZONE:
Lower section of east slope of Grand Turk just above highway. Vertical drop, 520 feet; length, 1,800 feet; average slope, 28 percent. Runout zone is 1,000 feet wide near highway. Section of track below contour line 10,600 feet m.s.l. probably is part of runout zone.

AVALANCHES:
Unimportant so far as highway is concerned.

CLASSIFICATION:
Large-erratic; Cataract North may run more easily than Cataract South.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Use of supporting structures is unlikely when extent of catchment basin and erratic occurrence of avalanches dangerous to the highway are considered. The gentle slope below 10,600 feet m.s.l. is favorable for diversion, retarding, or catchment structures.



Highway No. 550 --
Molas Divide
Photo: July 4, 1962

DEADWOOD (M-3)

LOCATION:
San Juan Mountains, Molas Divide north; east slope of a ridge that forms north border of Deadwood Gulch.

STARTING ZONE:
Irregular slope with cliffs; below timberline: 10,900-10,400 feet m.s.l.; 5 acres (2 ha).

TRACK:
Irregular east slope; not confined; vertical drop, 940 feet; length, 1,500 feet; average slope, 63 percent.

AVALANCHES:
Very seldom reaches road.

CLASSIFICATION:
Small-occasional.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Terrain and vegetation conditions are favorable for supporting structures.

Highway No. 550 --
Molas Divide
Photo: July 4, 1962

CHAMPION (M-4)

LOCATION:
San Juan Mountains, Molas Divide north; east slope on east shoulder of Sultan Mountain.

STARTING ZONE:
Irregular slope; rounded outcropping bedrock forms some cliffs; scattered timber; 11,000-10,400 feet m.s.l.; 15 acres (6 ha).

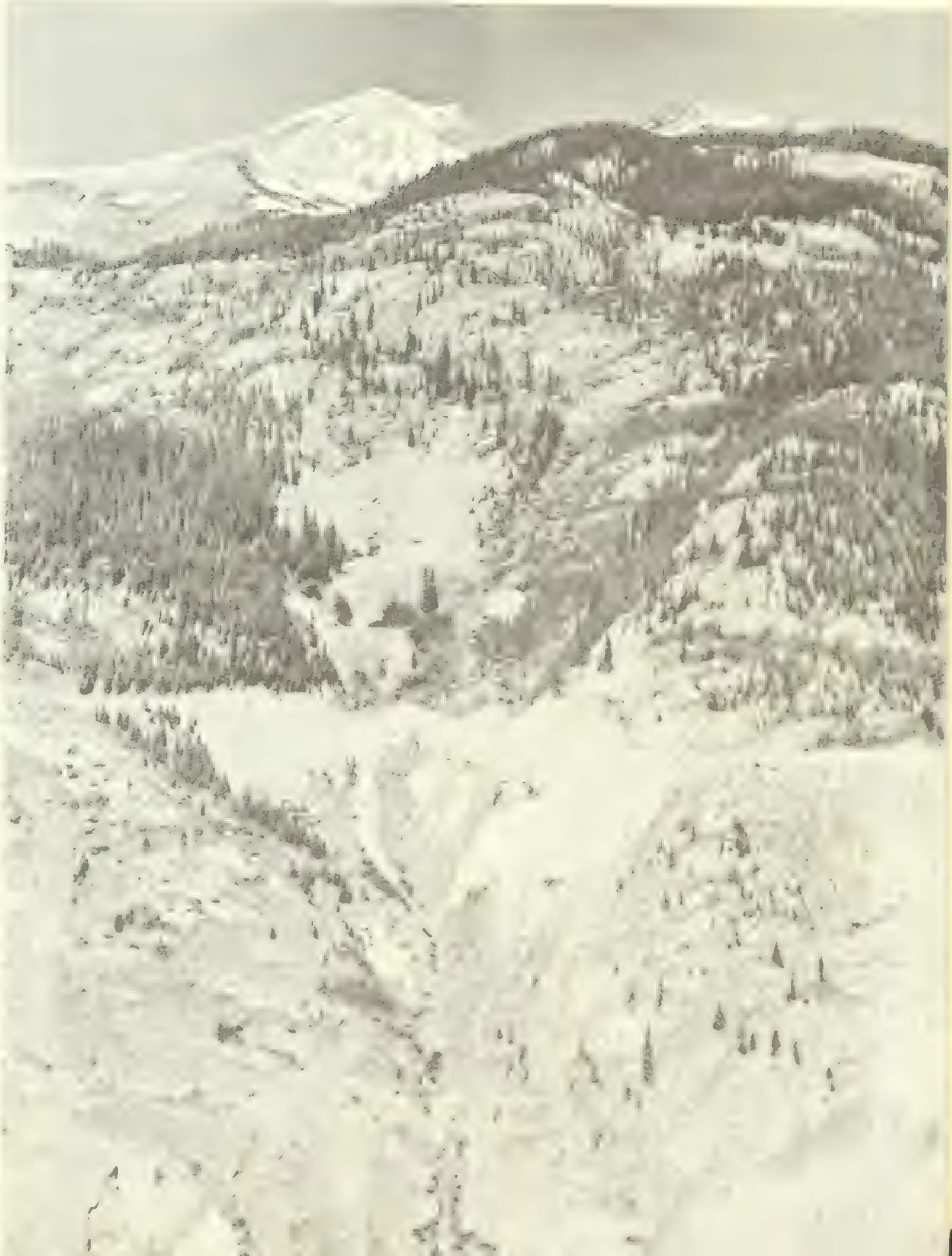
TRACK:
Trough-shaped slope above and below highway. For track above the highway--vertical drop, 1,000 feet; length, 1,700 feet; average slope, 60 percent. Track is 500 feet wide where it crosses highway.

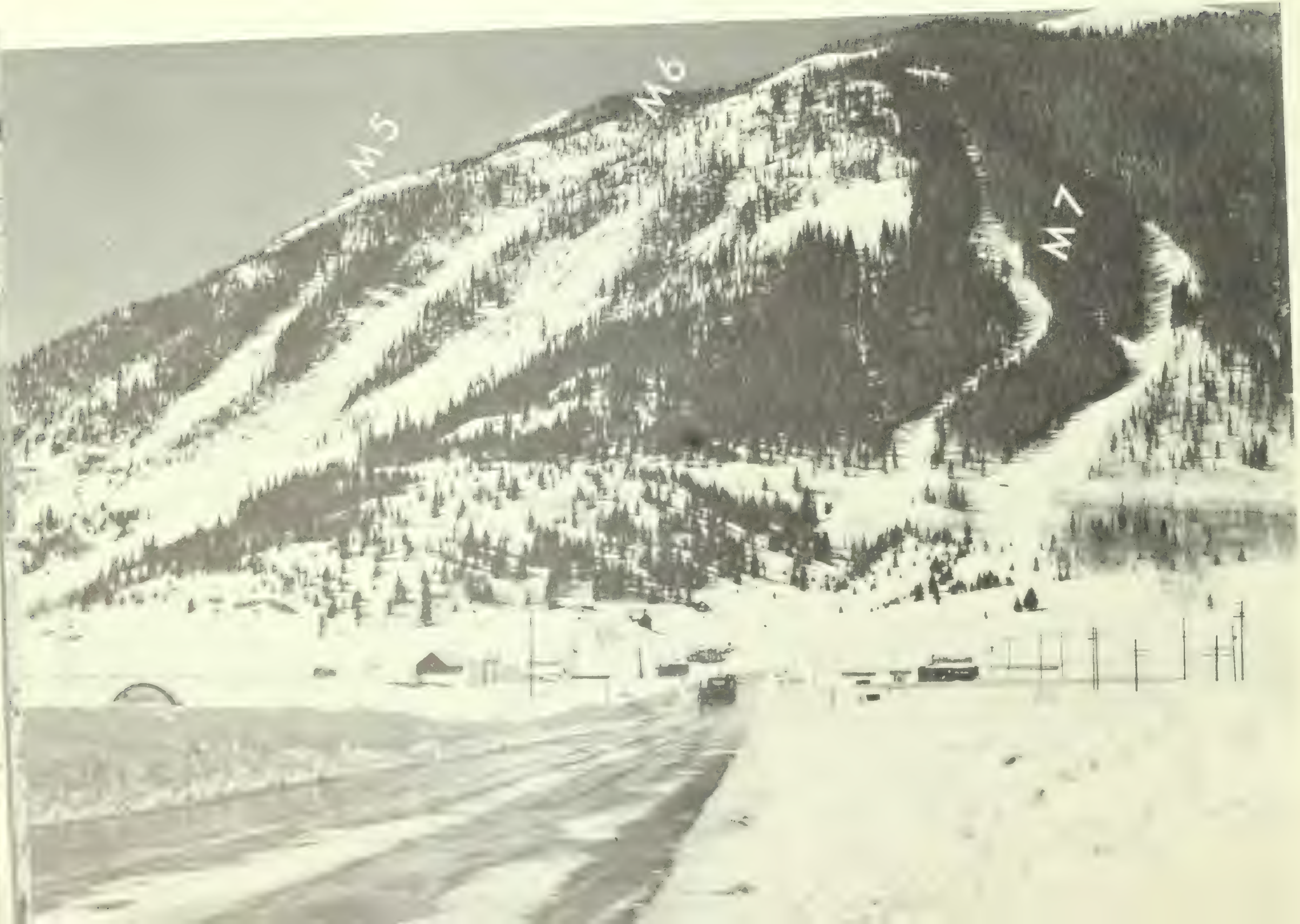
RUNOUT ZONE:
Alluvial flat of Animas River, 9,200 feet m.s.l.; well below highway.

AVALANCHES:
Dangerous avalanche that can run almost any time, but usually not large. Snow comes down a narrow slot and hits road at full speed; has taken a bus and a snowplow off road at different times. Artillery control has never been successful.

CLASSIFICATION:
Medium-occasional.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Terrain conditions are favorable for installation of supporting structures. Some field checks needed to locate starting spots.




M5
M6
M7

Highway No. 550 --
Molas Divide
Photo: July 4, 1962

PEACOCK (M-5)

LOCATION:
San Juan Mountains, Molas Divide north; northeast slope of the east shoulder of Sultan Mountain.

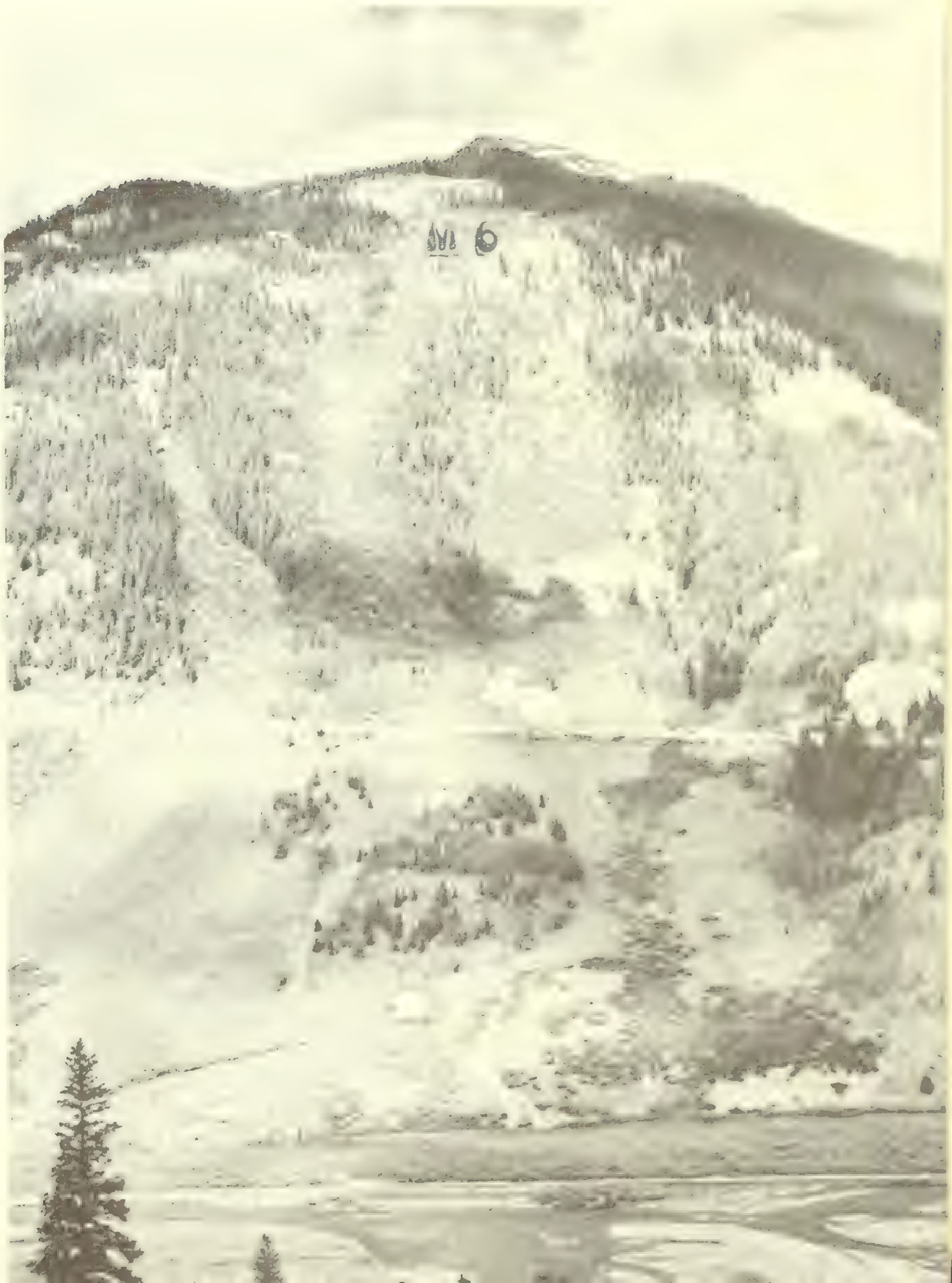
STARTING SPOT:
Top of narrow opening in woods; 10,800-10,200 feet m.s.l.; 1 acre (1/2 ha).

TRACK:
Very steep, narrow slot in timber; for section of track above highway--vertical drop, 1,080 feet; length, 1,500 feet; average slope, 72 percent. Avalanches cross highway at an elevation of 9,700 feet m.s.l. and continue downward to alluvial flat of Animas River, 9,200 feet m.s.l.

RUNOUT ZONE:
Alluvial flat of Animas River, 9,200 feet m.s.l.

CLASSIFICATION:
Small-occasional.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Supporting structures until aisle is afforested and avalanche is eliminated.



Highway No. 550 --
Molas Divide
Photo: March 24, 1962

JENNIE PARKER (M-6)

LOCATION:
San Juan Mountains, Molas Divide north; east slope of east shoulder of Sultan Mountain.

STARTING ZONE:
Irregular, partly bowl-shaped east slope; rocky benches and cliffs alternate with flatter sections of slope; sparsely timbered; 11,000-10,200 feet m.s.l. Difficult to delineate starting spots and extent of starting zone. 20 acres (8 ha).

TRACK:
Two paths separated by a timbered spot; vertical drop, 1,300 feet; length, 1,900 feet; average slope, 68 percent. Track is 600 feet wide where it crosses highway.

RUNOUT ZONE:
Gentle slopes below highway and alluvial flat of Animas River.

AVALANCHES:
One of the very bad slides in Molas Divide-Silverton area.

CLASSIFICATION:
Medium-frequent.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Because starting spots lie below timberline in a generally timbered area, control appears to be by supporting structures and afforestation. Starting spots are very indefinite and some cliffs may cause trouble, however. If careful field checks indicate that timber could be expected to come in after slides were controlled, then supporting structures would be recommended. If prospects for revegetation were poor, an avalanche shed would be best control method.

GLADSTONES (M-7)

LOCATION:
San Juan Mountains, Molas Divide north; northeast slope on the east shoulder of Sultan Mountain.

STARTING ZONE:
Two narrow aisles in a heavily timbered steep slope; 11,000-10,200 feet m.s.l.; 2-1/2 acres (1 ha).

TRACK:
Two gullylike paths in timber. Vertical drop, 1,400 feet; length, 2,500 feet; average slope, 58 percent.

RUNOUT ZONE:
Track crosses highway; avalanches run down to gentle section of slope below highway.

AVALANCHES:
Cause little trouble for road.

CLASSIFICATION:
Small-erratic.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Most obvious counter measure is to replant gullies to trees.

SUMMARY FOR HIGHWAY No. 550: RED MOUNTAIN PASS

This pass has a large number of avalanches; the list shows four bankslides (ROCKWALL, FENCE, SNOWFLAKE, and TWIN BRIDGES) and 30 avalanches. On the south side of Red Mountain Pass from Brown's Gulch near the BROOKLYNS to Porphyry Gulch near the summit of the Pass, there is a nearly continuous belt of avalanches for 3-1/2 miles along the highway. Red Mountain Pass also has the biggest and most striking avalanches--EAST GUADALUPE with its 150-acre catchment basin, and EAST RIVERSIDE with its tremendous shooting track.

The strip map compiled by the Colorado Highway Department shows location and names of several avalanches or slides along U. S. Highway 550 which could not be located exactly on the terrain. These are BENNY LONG, SILVER LEDGE MILL, ROCKWALL, SILVER LEDGE MINE, FENCE, SNOWFLAKE, and BARSTOW. On the other hand, some avalanches that have been added to the list are: BATTLE SHIP, IMOGENE, KING, GOVERNOR GULCH, GALENA LION GULCH, IRONTON PARK, and WEST GUADALUPE.

To help evaluate control measures, the numerous avalanches are classified into groups that show similar features, and/or require the same control measures:

Group 1: Boulder Slopes--WATER GAGE, OLD SOUTH MINERAL ROAD, PIT
Group 2: ZUNI
Group 3: CEMENT FILL
Group 4: Mineral Gorge--BATTLE SHIP, IMOGENE
Group 5: Brooklyns -- BENNY LONG, BROOKLYNS, CEMETERY, TWIN CROSSING, NORTH MINERAL BRIDGE
Group 6: Bullion King -- MULESHOE, TELESCOPE, EAGLE
Group 7: Silver Mine -- PORCUPINE, SILVER LEDGE MILL, ROCKWALL, SILVER LEDGE MINE
Group 8: FENCE, SNOWFLAKE
Group 9: BLUE POINT, WILLOW, BARSTOW
Group 10: Mountain King--GOVERNOR GULCH, GALENA LION GULCH
Group 11: IRONTON PARK
Group 12: South Entrance--EAST GUADALUPE, WEST GUADALUPE, SLIPPERY JIM, EAST RIVERSIDE, WEST RIVERSIDE
Group 13: Uncompahgre Gorge--DUNSMORE, MOTHER CLINE, SILVER POINT, JACK POT
Group 14: Afforestations -- LOWER CEMENT FILL, BARTON

The Cement Fill, Brooklyns, Bullion King, and South Entrance groups are large, very bad avalanches. BLUE POINT is small, but troublesome. The Ironton Park and Mineral Gorge groups have large avalanches that cross the road only under extreme conditions.

As emphasized several places in this report, control measures should begin with avalanche groups where the type of control is obvious. The Afforestations group can be controlled by structures in the starting zone, followed by afforestation. Avalanche sheds or tunnels are needed for the South Entrance group. SLIPPERY JIM, within this group, might be controlled in the starting zone after the starting spots are located, but it would be better to control the entire group at one time with avalanche sheds. The Blue Point, Ironton Park, Silver Mine, and Fence-Snowflake groups can be controlled easily with supporting structures. The last three groups are less important than the first.

Control will be difficult for the Brooklyns, Cement Fill, and Bullion King groups. Supporting structures are recommended for the Brooklyns group, and avalanche sheds for the other two, although the best type of control is uncertain without further study.

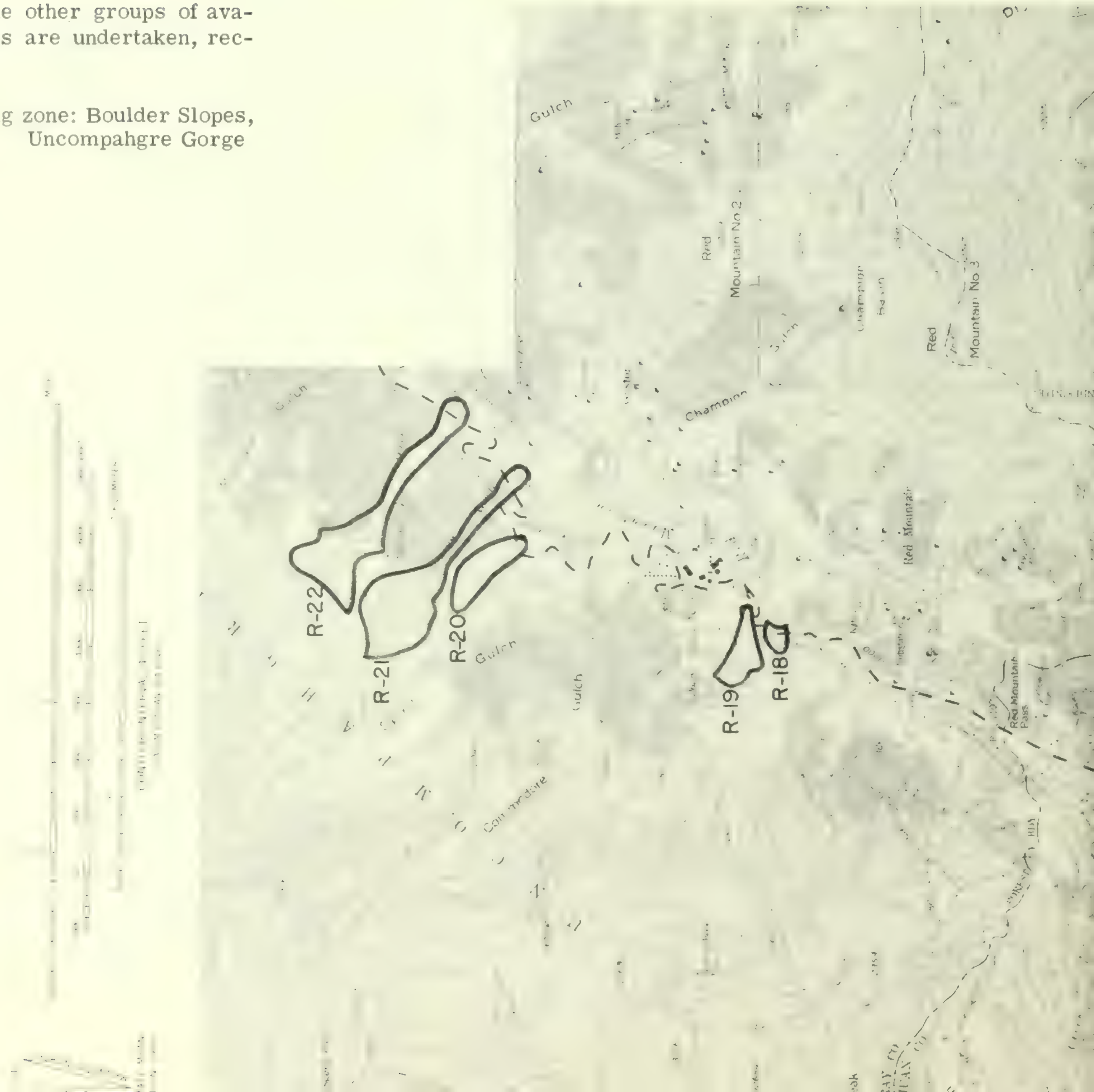
Control is not pressing for the other groups of avalanches, but when control measures are undertaken, recommendations are:

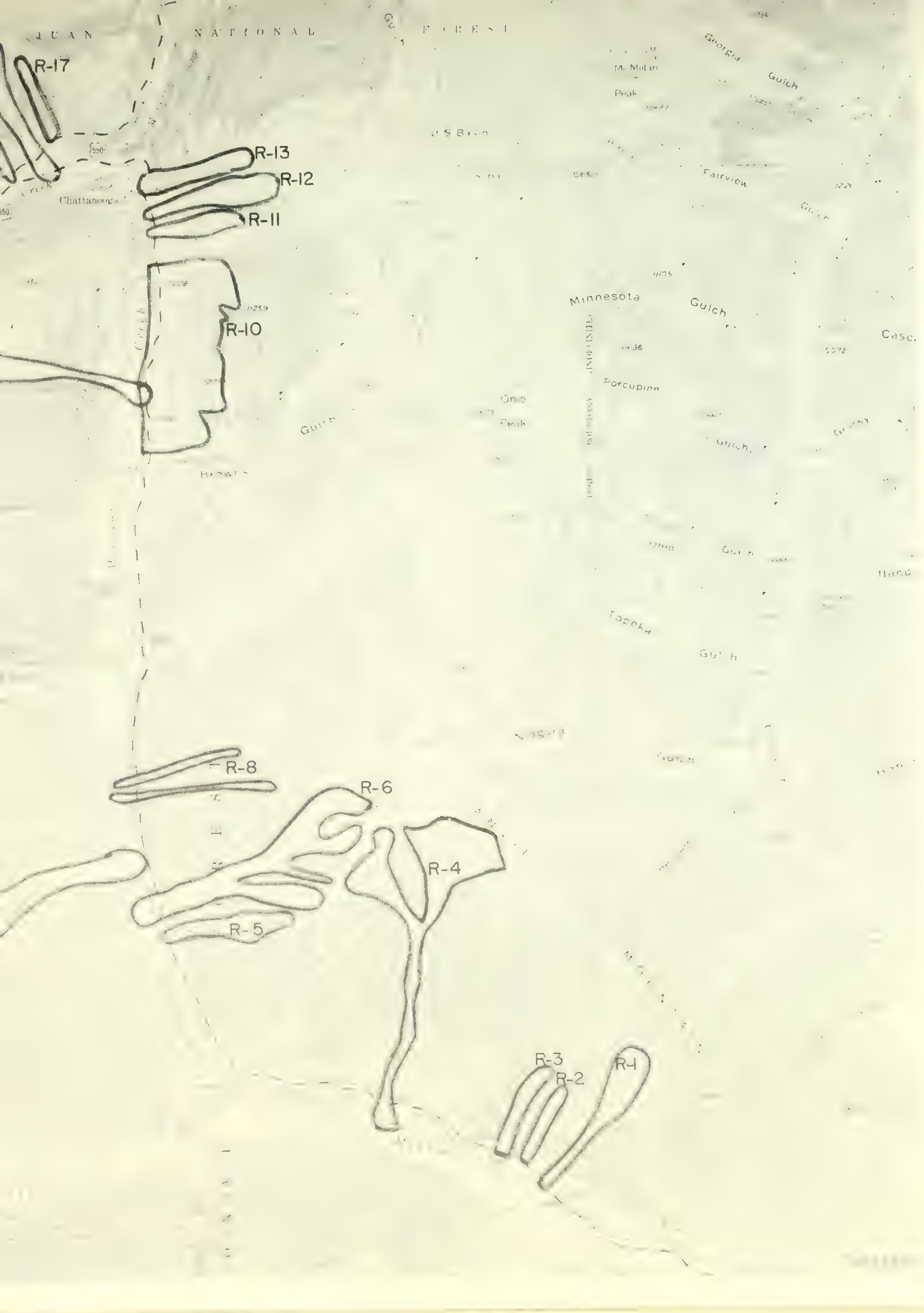
Supporting structures in the starting zone: Boulder Slopes, Uncompahgre Gorge

Avalanche sheds: Zuni

Catchment dams: Mineral Gorge

Diversion dams: Mountain King




SAN JUAN NATIONAL FOREST
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R-2
R-1
Chattanooga
Creek
M. Mullan Peak
Georgia Gulch
Fairview
U S Basin
Minnesota Gulch
Porcupine
Ohio Peak
Gulch
Ohio Gulch
Topeka Gulch
Casc.
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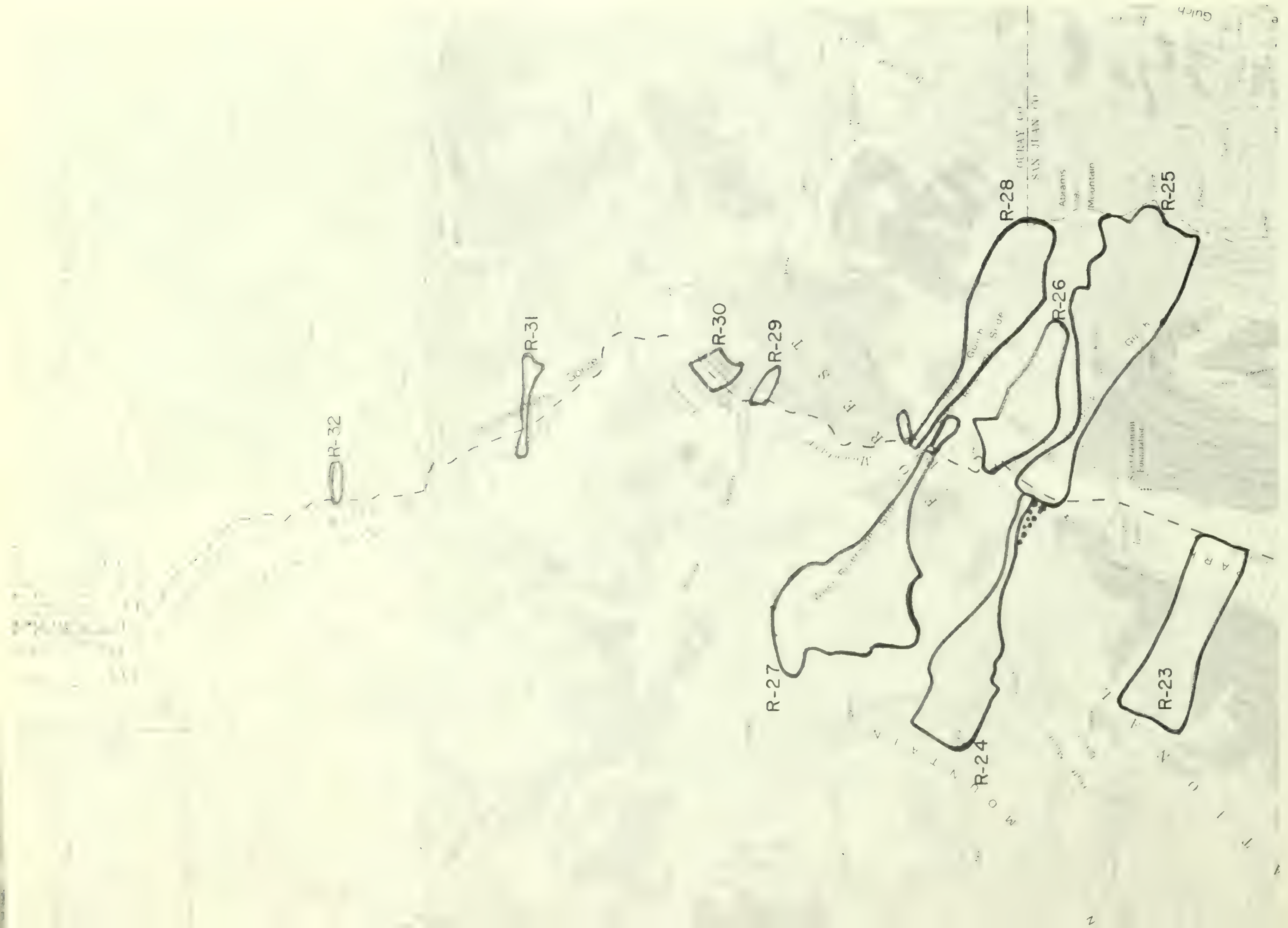
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R-32
OURAY CO
SAN JUAN CO
Abrams
Mountain
Gulch
Gorge

WATER GAGE (R-1)

LOCATION:
San Juan Mountains, Red Mountain Pass south; southwest slope of Anvil Mountain.

CATCHMENT BASIN:
Trough in southwest slope of Anvil Mountain below timberline; 11,300-10,400 feet m.s.l.; 20 acres (8 ha).

TRACK:
Gully with steep slopes in upper part and moderate slopes in lower part; vertical drop, 1,900 feet; length, 3,500 feet; average slope, 54 percent.

RUNOUT ZONE:
Some avalanches may stop on lower part of track, which has a length of 2,000 feet and an average slope of 40 percent. Big, fast-moving snow masses will reach highway and flat bed of Mineral Creek.

AVALANCHES:
Not much trouble on highway in recent years.

CLASSIFICATION:
Medium-erratic.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Structural control would not be economical for two reasons: big snow masses are unusual because of exposure and elevation; and rock and talus are not favorable for foundation of supporting structures. Reforestation probably would not be successful.

OLD SOUTH MINERAL ROAD (R-2)

LOCATION:
San Juan Mountains, Red Mountain Pass south; southwest slope of Anvil Mountain.

STARTING ZONE:
Southwest-facing cliffs and very steep boulder field; below timberline; 10,700-10,300 feet m.s.l.; 5 acres (2 ha).

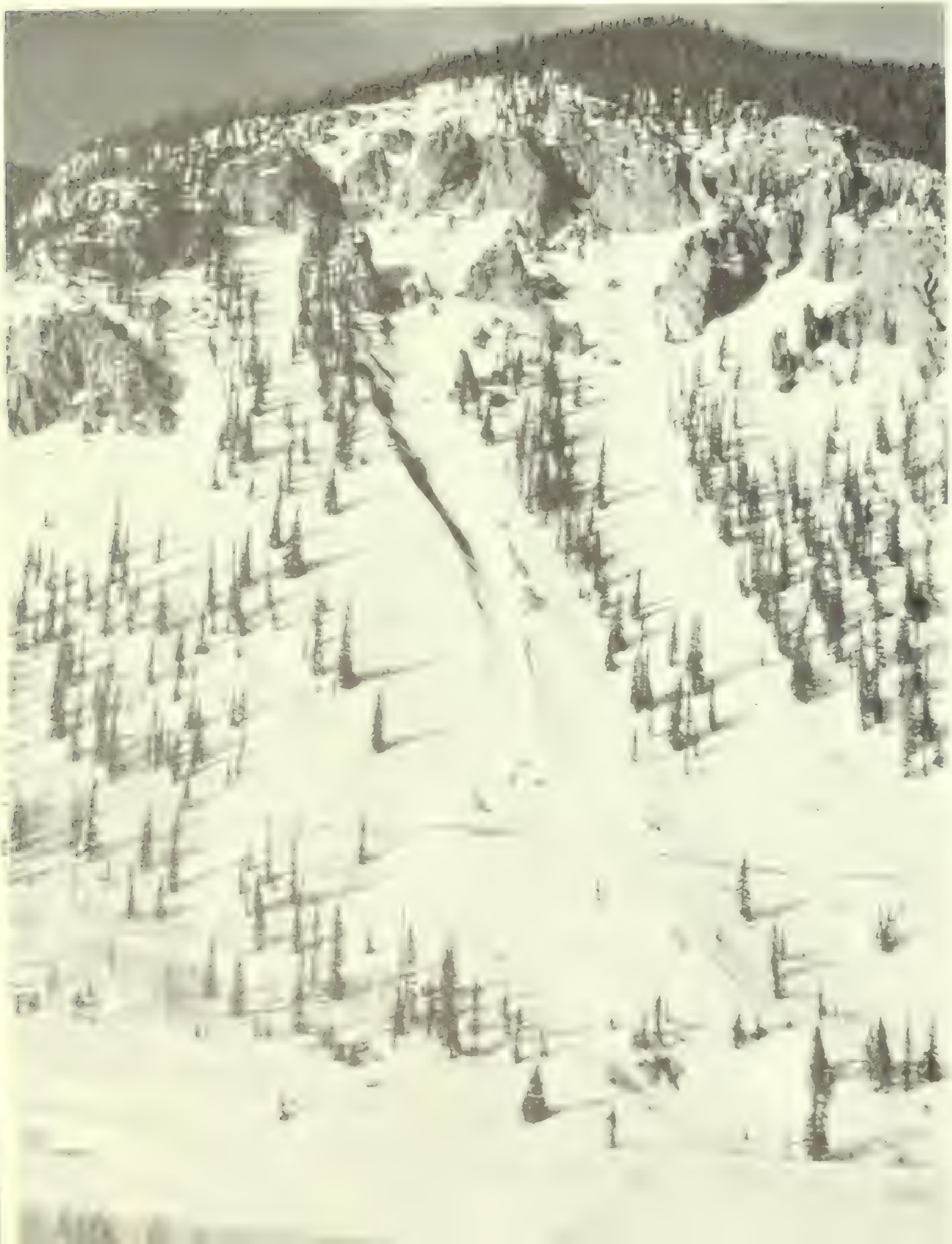
TRACK:
Slightly expressed gully in scree slope running down to road. Lower part, gentle; vertical drop, 1,200 feet; length, 1,800 feet; average slope, 67 percent.

RUNOUT ZONE:
Some avalanches stop in lower section of track which is 1,000 feet long, with 50-percent average slope. Big, fast-moving snow masses reach the highway.

AVALANCHES:
Little trouble on highway in recent years.

CLASSIFICATION:
Small-erratic.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Since occurrence is erratic and terrain shows some cliffs and is unstable, no structural control can be recommended. The dry southerly exposure is unfavorable for reforestation.



Highway No. 550 --
Red Mountain Pass
Photo: March 25, 1962

PIT (R-3)

LOCATION:
San Juan Mountains, Red Mountain Pass south; southwest slope of Anvil Mountain.

STARTING ZONE:
Southwest-facing cliffs and very steep boulder field; below timberline; 10,800-10,500 feet m.s.l.; 5 acres (2 ha).

TRACK:
Slightly expressed gully in boulder slope running down to road. Vertical drop, 1,400 feet; length, 2,200 feet; average slope, 64 percent. Lower part has average slope of only 55 percent.

RUNOUT ZONE:
Smaller avalanches may stop in lower section of track; larger snow masses will reach highway.

AVALANCHES:
Runs to road each year; brings rocks and debris with it.

CLASSIFICATION:
Small-frequent.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Runout zone is too steep for effective use of retarding or catchment structures, although such structures might bring some relief from rockfalls and debris. Supporting structures cannot be recommended without further study because of the cliffs and the unstable ground. A small earth mound has been built above the road for avalanche control. This splits avalanches into two parts, but is not completely effective.

Highway No. 550 --
Red Mountain Pass
Photo: March 25, 1962

ZUNI (R-4)

LOCATION:
San Juan Mountains, Red Mountain Pass south; south slope of Anvil Mountain.

CATCHMENT BASIN:
Two big basins in south slope of Anvil Mountain; above and below timberline; 12,200-11,400 feet m.s.l.; 60 acres (25 ha).

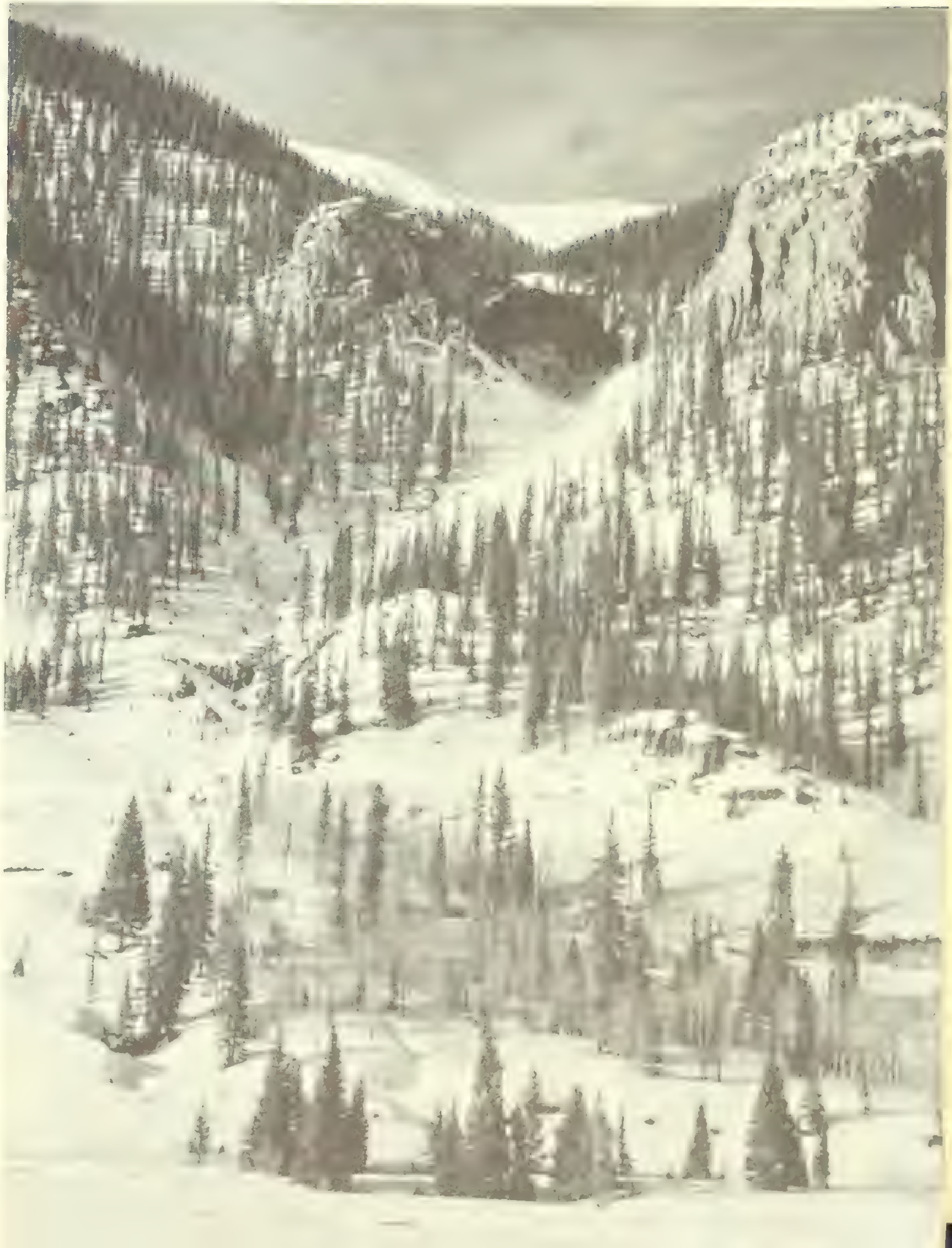
TRACK:
Narrow and curved rocky gully of Zuni Gulch; vertical drop, 2,580 feet; length, 6,000 feet; average slope, 43 percent. Longitudinal profile of track is very irregular.

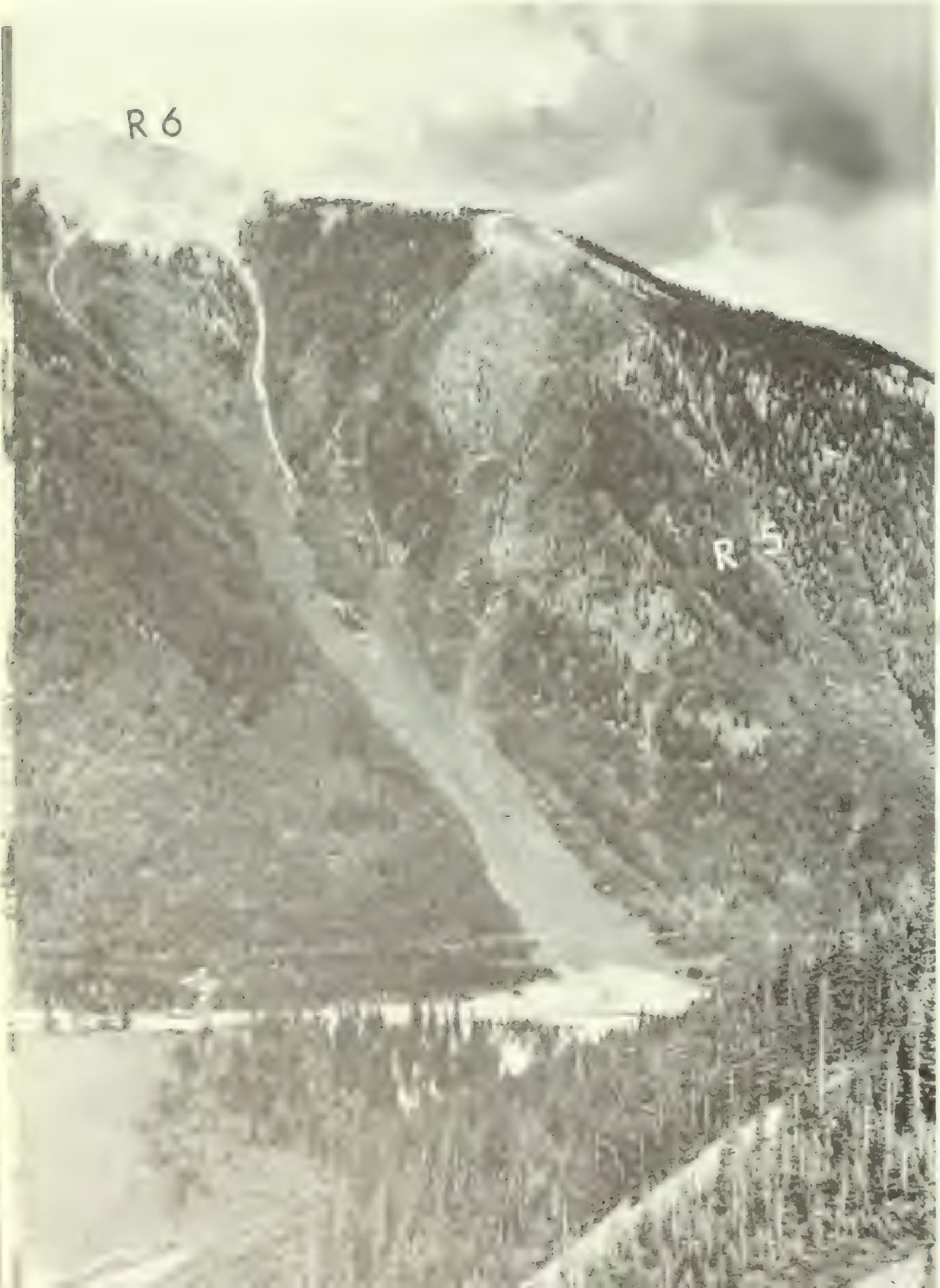
RUNOUT ZONE:
Alluvial fan of Zuni Gulch and flat bed of Mineral Creek; average slope, 22 percent; indefinite lateral limits.

AVALANCHES:
Ran big in 1932 and 1952.

CLASSIFICATION:
Large-erratic.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Runs very seldom, but when it runs, very big snow masses with much debris are expected. If control is desired, the only possibility would be an avalanche shed.





Highway No. 550 --
Red Mountain Pass
Photo: July 3, 1962

LOWER CEMENT FILL (R-5)

LOCATION:
San Juan Mountains, Red Mountain Pass south; west slope of Anvil Mountain.

STARTING ZONE:
Indefinite; west-facing slope with scattered timber; below timberline; 11,400-10,800 feet m.s.l.; 7 acres (3 ha).

TRACK:
Depression in slope: upper part is steep; lower part, moderate; vertical drop, 1,200 feet; length, 1,800 feet; average slope, 67 percent. Aspen and spruce are regenerating naturally in track.

RUNOUT ZONE:
Lower section of slope; length, 800 feet; average slope, 45 percent.

CLASSIFICATION:
Small-frequent.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Good chance for control with supporting structures and afforestation.

CEMENT FILL (R-6)

LOCATION:
San Juan Mountains, Red Mountain Pass south; west slope of Anvil Mountain.

CATCHMENT BASIN:
Bowl-shaped depression on west slope of Anvil Mountain; above and below timberline; 12,400-10,600 feet m.s.l.; 75 acres (30 ha); catchment basin has four compartments.

TRACK:
Bowl-shaped depression on slope; vertical drop, 2,600 feet; length, 5,000 feet; average slope--upper half, 58 percent, lower half, 39 percent; track is 500 feet wide where it crosses highway.

RUNOUT ZONE:
Mineral River gorge below the highway.

CLASSIFICATION:
Large-occasional.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Catchment basin is too extended to be controlled economically with supporting structures. No possibilities exist for diversion or retarding structures. Avalanche shed with guide dams is recommended.

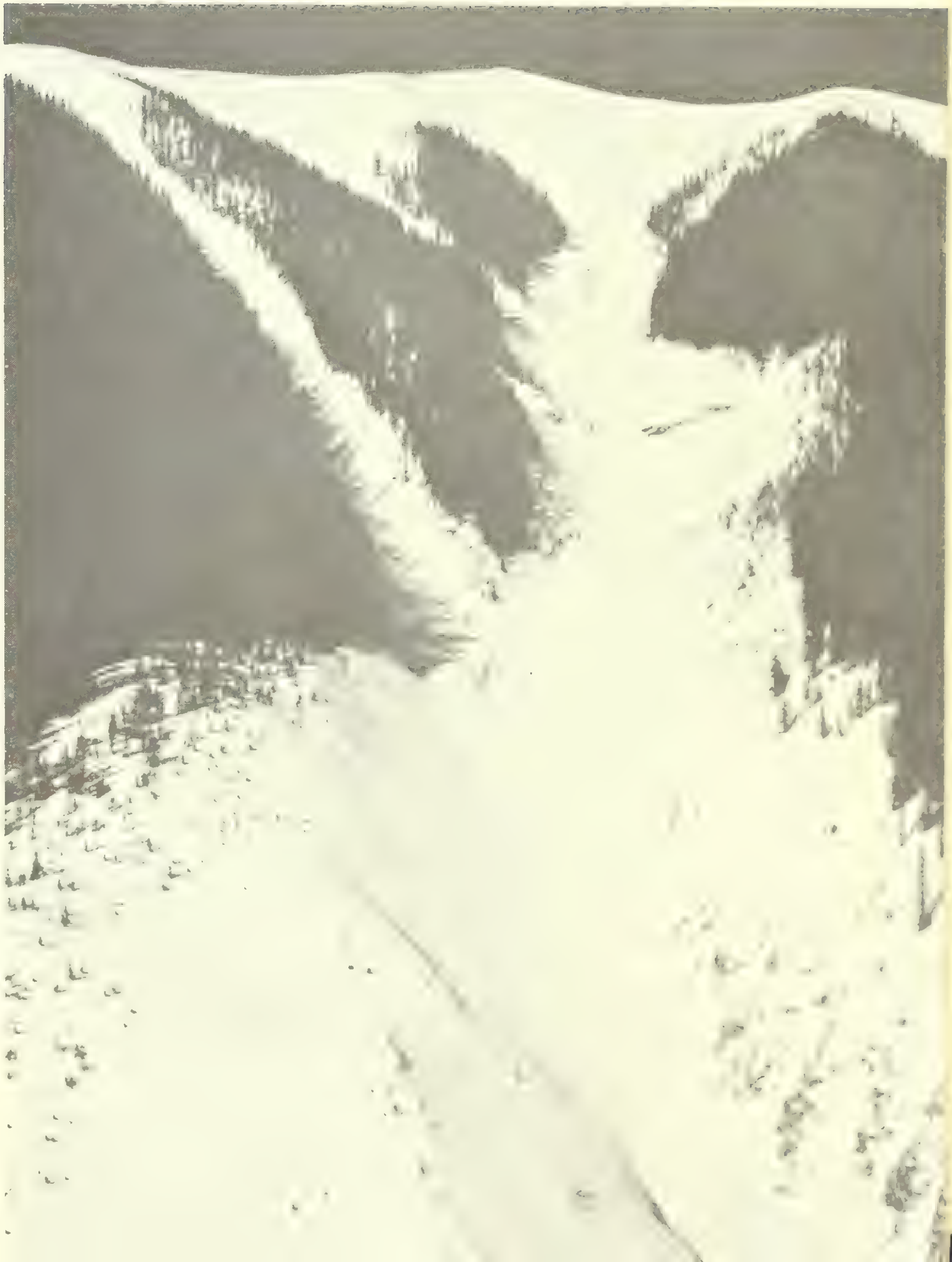
Highway No. 550 --
Red Mountain Pass
Photo: March 25, 1962

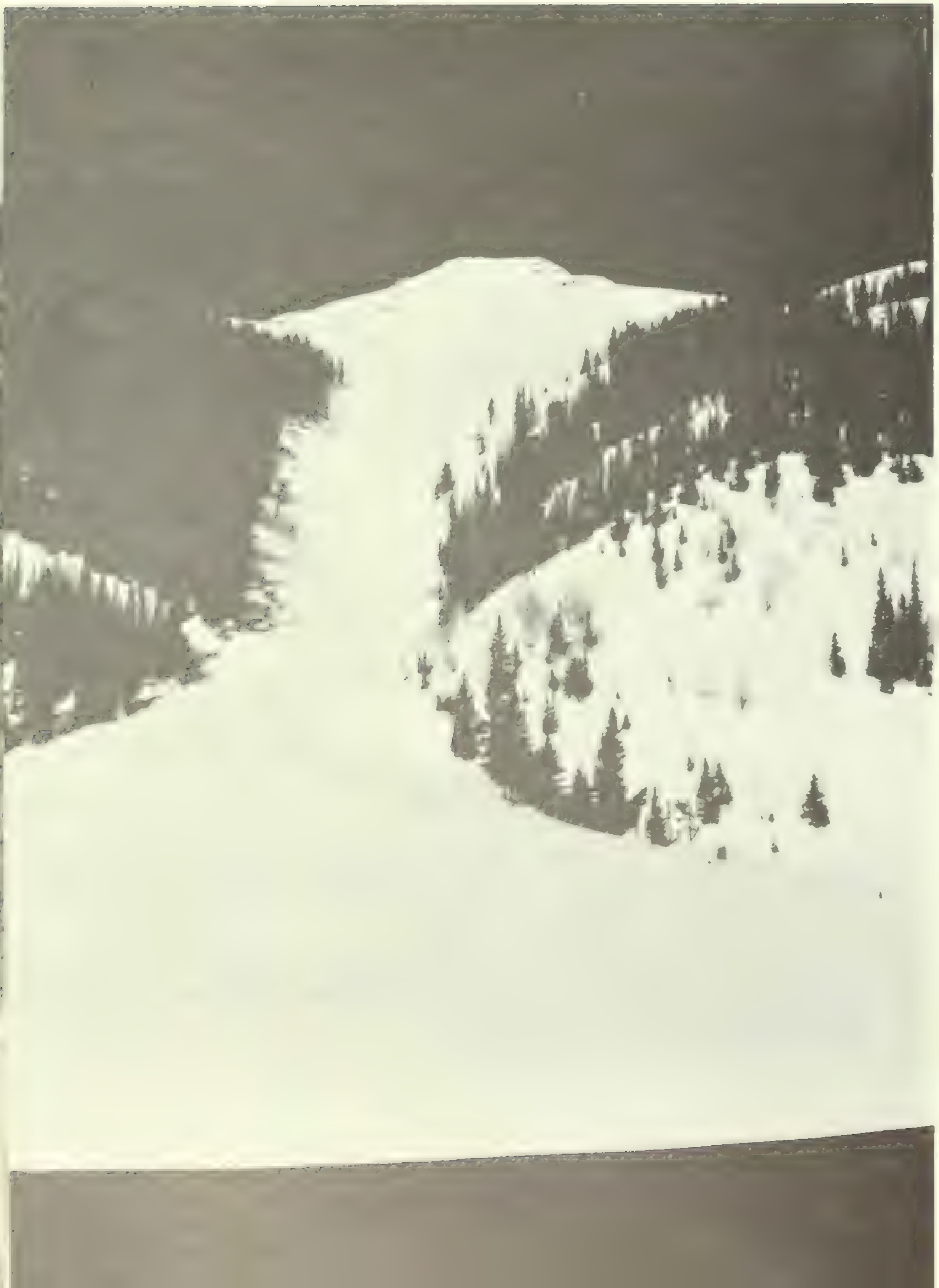
BATTLE SHIP (R-7)

LOCATION:
San Juan Mountains, Red Mountain Pass south; northeast slope of summit spot elevation, 12,442.
CATCHMENT BASIN:
Three basins on northeast slope; above timberline; 12,200-11,400 feet m.s.l.; 45 acres (18 ha).
TRACK:
Narrow gully; vertical drop, 2,500 feet; length, 5,600 feet; average slope, 45 percent.
RUNOUT ZONE:
Highway runs 250 feet above Mineral Creek on opposite mountain slope. Small, wet snow avalanches stop in Mineral Creek ravine; in bad conditions, dry dust avalanches ascend slope and reach highway.
CLASSIFICATION:
Large-occasional; seldom reaches highway.
POSSIBILITIES FOR STRUCTURAL CONTROL:
If considered necessary, a catchment dam could be built to protect highway from influence of avalanche blast.

BARTON (R-8) (No photo)

LOCATION:
San Juan Mountains, Red Mountain Pass south; west slope of Anvil Mountain.
STARTING SPOTS:
Two narrow, steep gullies in heavily timbered slope; 11,400-10,800 feet m.s.l.; 5 acres (2 ha).
TRACKS:
Gullylike openings in the forest, long but narrow; vertical drop, 1,400 feet; length, 2,900 feet; average slope, 48 percent.
RUNOUT ZONE:
Some avalanches stop on lower, more gentle section of track above highway. Bigger and faster moving snow masses cross highway and shoot down into gorge of Mineral Creek.
CLASSIFICATION:
Small-frequent.
POSSIBILITIES FOR STRUCTURAL CONTROL:
Supporting structures with afforestation of forest openings.





Highway No. 550 --
Red Mountain Pass
Photo: March 25, 1962

IMOGENE (R-9)

LOCATION:
San Juan Mountains, Red Mountain Pass south; east slope of Imogene Mountain; spot elevation, 12,692.
CATCHMENT BASIN:
Trough in east slope of Imogene Mountain; above timberline; 12,300-11,600 feet m.s.l.; 15 acres (6 ha).
TRACK:
Narrow gully; vertical drop, 1,900 feet; length, 3,800 feet; average slope, 50 percent.
RUNOUT ZONE:
Alluvial fan of gully and bottom lands of Mineral Creek; length, 1,100 feet; average slope, 25 percent.
AVALANCHES:
No records. A dry, dust avalanche may cross Mineral Creek and reach highway on opposite bank.
CLASSIFICATION:
Medium-occasional.
POSSIBILITIES FOR STRUCTURAL CONTROL:
If control is considered necessary, a catchment dam could be built to protect highway from influence of avalanche blast.

BLACKBURN (No photo)

LOCATION:
San Juan Mountains, Red Mountain Pass south; west slope of southwest shoulder of Ohio Peak; between BARTON (R-8) and IMOGENE (R-9) on east side of road; exact location not determined in field so not designated on topographic map.
STARTING ZONE:
Steep scarp above highway; scattered timber; about 10,200 feet m.s.l.; 2-1/2 acres (1 ha).
TRACK:
No confined track; avalanches are really just bankslides.
CLASSIFICATION:
Small-occasional.
POSSIBILITIES FOR STRUCTURAL CONTROL:
Supporting structures and afforestation.

Highway No. 550 --
Red Mountain Pass
Photo: January 3, 1962

BROOKLYNS (R-10)

LOCATION:
San Juan Mountains, Red Mountain Pass south; west slope on the northwest shoulder of Ohio Peak.

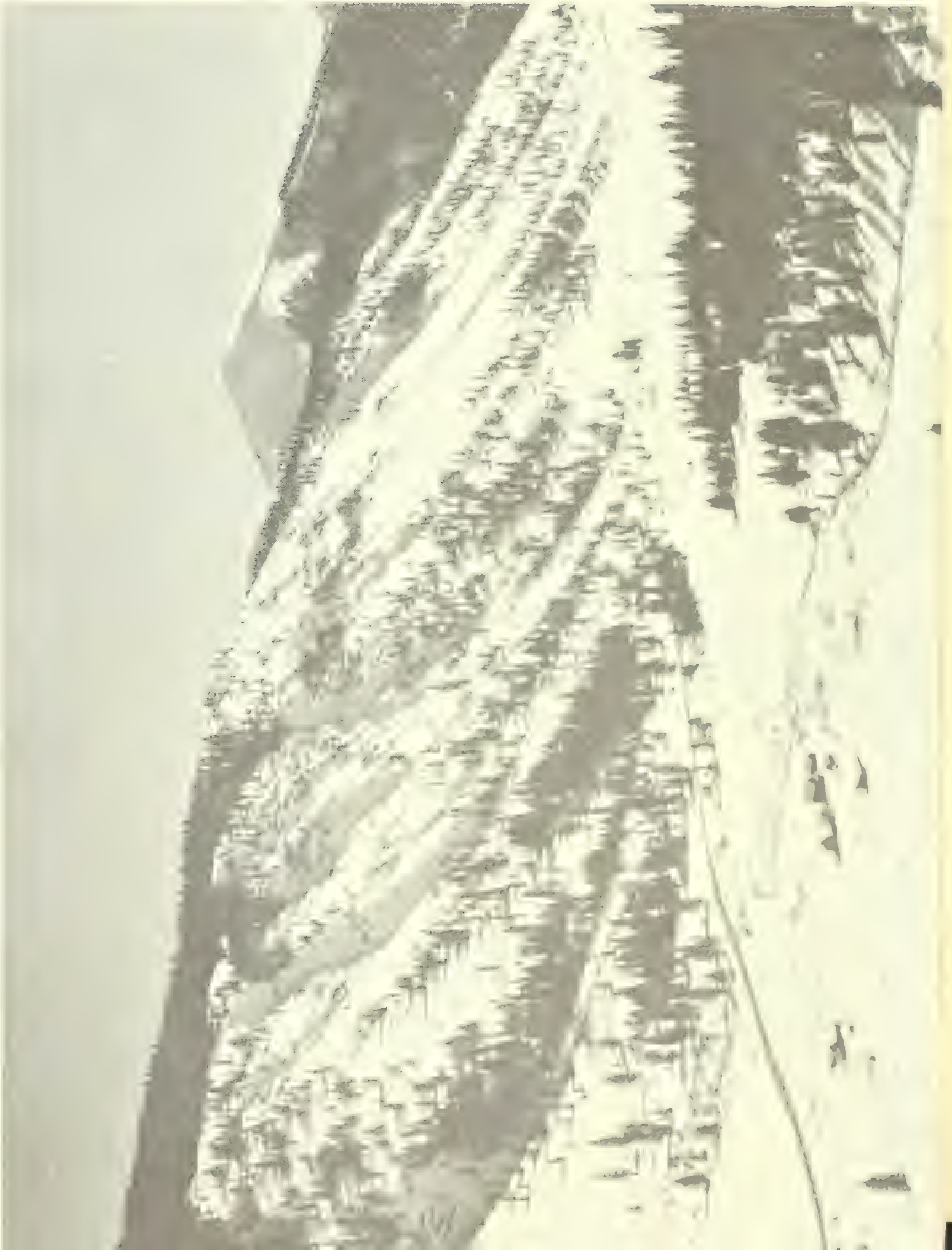
STARTING ZONE:
In cliffs at top and on steep talus slopes below, with a few widely scattered trees and scattered clumps of timber; below timberline; 11,200-10,600 feet m.s.l.; 50 acres (20 ha).

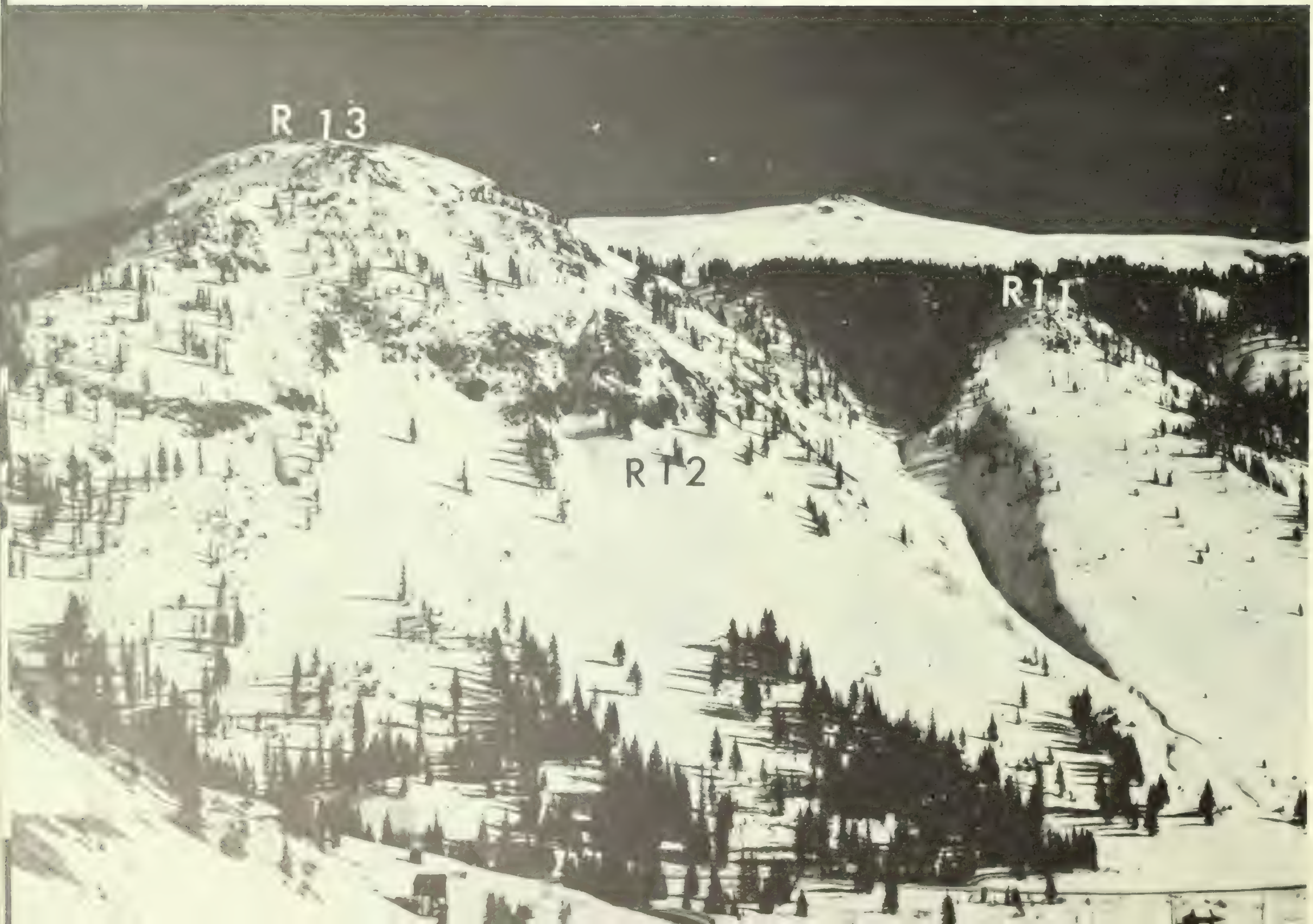
TRACKS:
Many groovelike depressions in slope; vertical drop, 1,000 feet; length, 1,600 feet; average slope, 63 percent. Individual tracks are so many and so close together that whole slope avalanches for a distance of 4,000 feet.

RUNOUT ZONE:
Some snow may stop in lower section of tracks above highway. This section has a length of 500 feet and an average slope of 48 percent. Most snow, however, crosses highway and runs to bed of Mineral Creek.

CLASSIFICATION:
Large-frequent.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Although the rugged top of starting zones and scree slopes give some problems, control by supporting structures is possible for a considerable number of the tracks.

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Highway No. 550 --
Red Mountain Pass
Photo: January 3, 1962

CEMETERY (R-11)

LOCATION:
San Juan Mountains, Red Mountain Pass south; west slope of point 12,171.

STARTING ZONE:
Steep, uniform slope; below timberline; 11,200-10,600 feet m.s.l.; 5 acres (2 ha).

TRACK:
Not definite; upper half of track is steep slope--vertical drop, 800 feet; length, 1,200 feet; average slope, 67 percent; lower half is gentle slope--vertical drop, 160 feet; length, 700 feet; average slope, 23 percent.

RUNOUT ZONE:
Small avalanches stop in lower half of track. Larger snow masses run across highway to Mineral Creek; runout zone not well defined.

CLASSIFICATION:
Small-frequent.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Can be controlled by supporting structures or possibly by retarding and catching structures.

TWIN CROSSING (R-12)

LOCATION:
San Juan Mountains, Red Mountain Pass south; southwest slope of point 12,171.

CATCHMENT BASIN:
Bowl-shaped, rugged depression in southwest-facing slope; below timberline; 11,600-10,800 feet m.s.l.; 15 acres (6 ha).

TRACK:
A gullylike depression in slope; upper half--vertical drop, 1,000 feet; length, 1,700 feet; average slope, 59 percent; lower half--vertical drop, 560 feet; length, 1,600 feet; average slope, 35 percent.

RUNOUT ZONE:
Small avalanches stop in lower half of track; large avalanches cross highway and stop in Mineral Creek flats. Width of runout zone, indefinite.

CLASSIFICATION:
Medium-frequent.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Supporting structures are possible, but difficulties should be expected because of ruggedness of starting zone.

NORTH MINERAL BRIDGE (R-13)

LOCATION:
San Juan Mountains, Red Mountain Pass south; west slope of point 12,171.

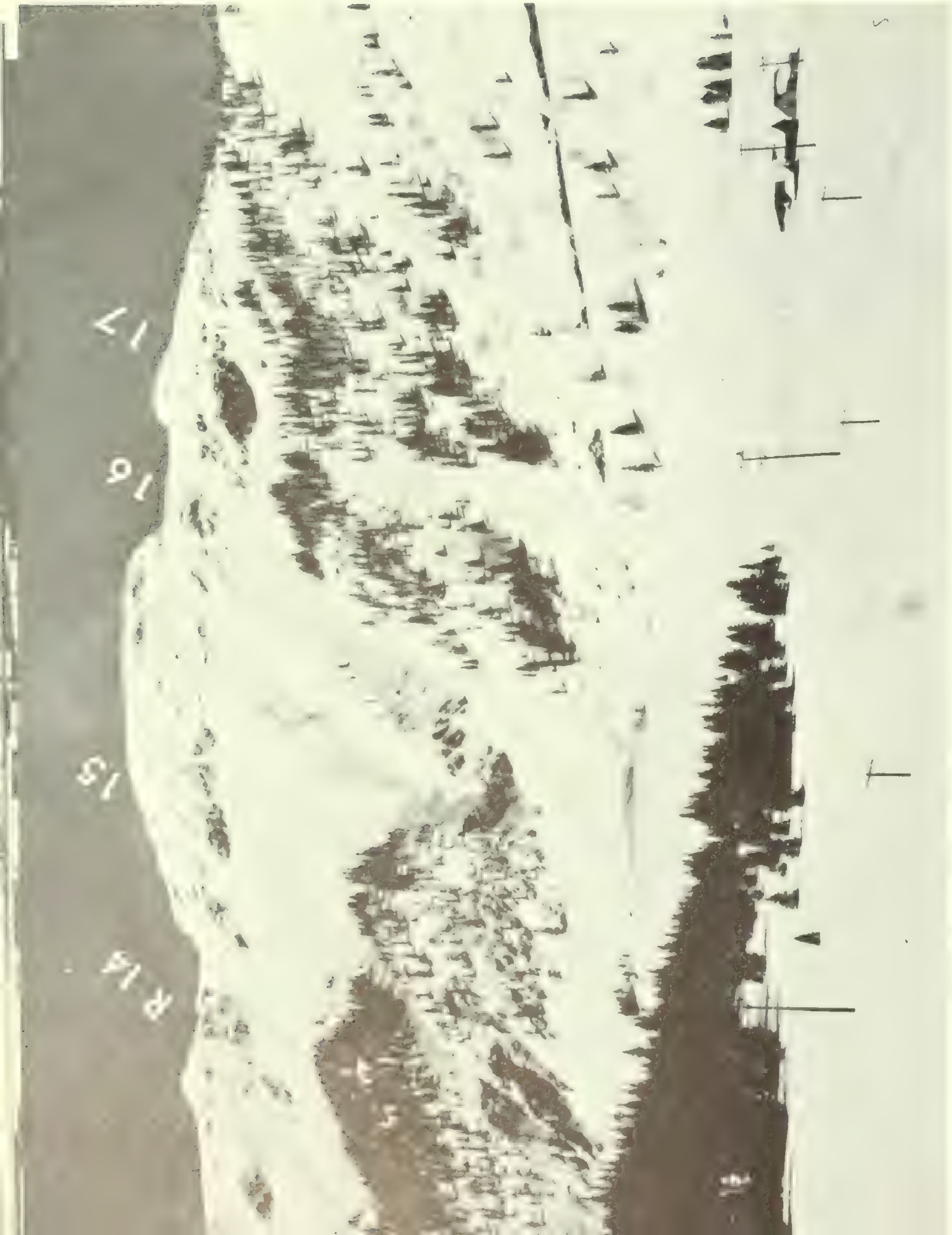
STARTING ZONE:
Rugged, irregular slope with cliffs; starting spots are not confined. Below timberline; 11,600-10,800 feet m.s.l.; 10 acres (4 ha).

TRACK:
Not confined; upper half--vertical drop, 800 feet; length, 1,000 feet; average slope, 80 percent; lower half--vertical drop, 520 feet; length, 1,200 feet; average slope, 43 percent.

RUNOUT ZONE:
Small avalanches stop in lower half of track: larger ones cross the highway and run to Mineral Creek flats.

CLASSIFICATION:
Medium-frequent.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Supporting structures not recommended because of rugged starting zone: retarding structures might be possible.



Highway No. 550 --
Red Mountain Pass
Photo: March 24, 1962

MULESHOE (R-14)

LOCATION:
San Juan Mountains, Red Mountain Pass south; southeast slope of Bullion King Mountain.
CATCHMENT BASIN:
Bowl-shaped depression on slope; above timberline; some cliffs; 12,700-11,700 feet m.s.l.; 20 acres (8 ha).
TRACK:
Very steep gully; vertical drop, 2,100 feet; length, 3,100 feet; average slope, 68 percent.
RUNOUT ZONE:
Alluvial fan of gully and valley bottom of Mill Creek; length, 800 feet; average slope, 25 percent. Runout zone is indefinite.
CLASSIFICATION:
Medium-frequent.
POSSIBILITIES FOR STRUCTURAL CONTROL:
Diversion dam.

TELESCOPE (R-15)

LOCATION:
San Juan Mountains, Red Mountain Pass south; southeast slope of Bullion King Mountain.
CATCHMENT BASIN:
Uniform slope topped with a cliff; above timberline; 12,200-11,800 feet m.s.l.; 5 acres (2 ha).
TRACK:
Gullylike depression in slope; vertical drop, 1,420 feet; length, 2,200 feet; average slope, 65 percent. Lower part of track is a series of cliffs formed from bedrock.
RUNOUT ZONE:
Alluvial fan of gully; length, 700 feet; average slope, 40 percent. Highway cuts fan in half.
CLASSIFICATION:
Small-frequent.
POSSIBILITIES FOR STRUCTURAL CONTROL:
Supporting structures in the starting zone or an avalanche shed, depending upon the decision made for the control of the neighboring EAGLE avalanche.

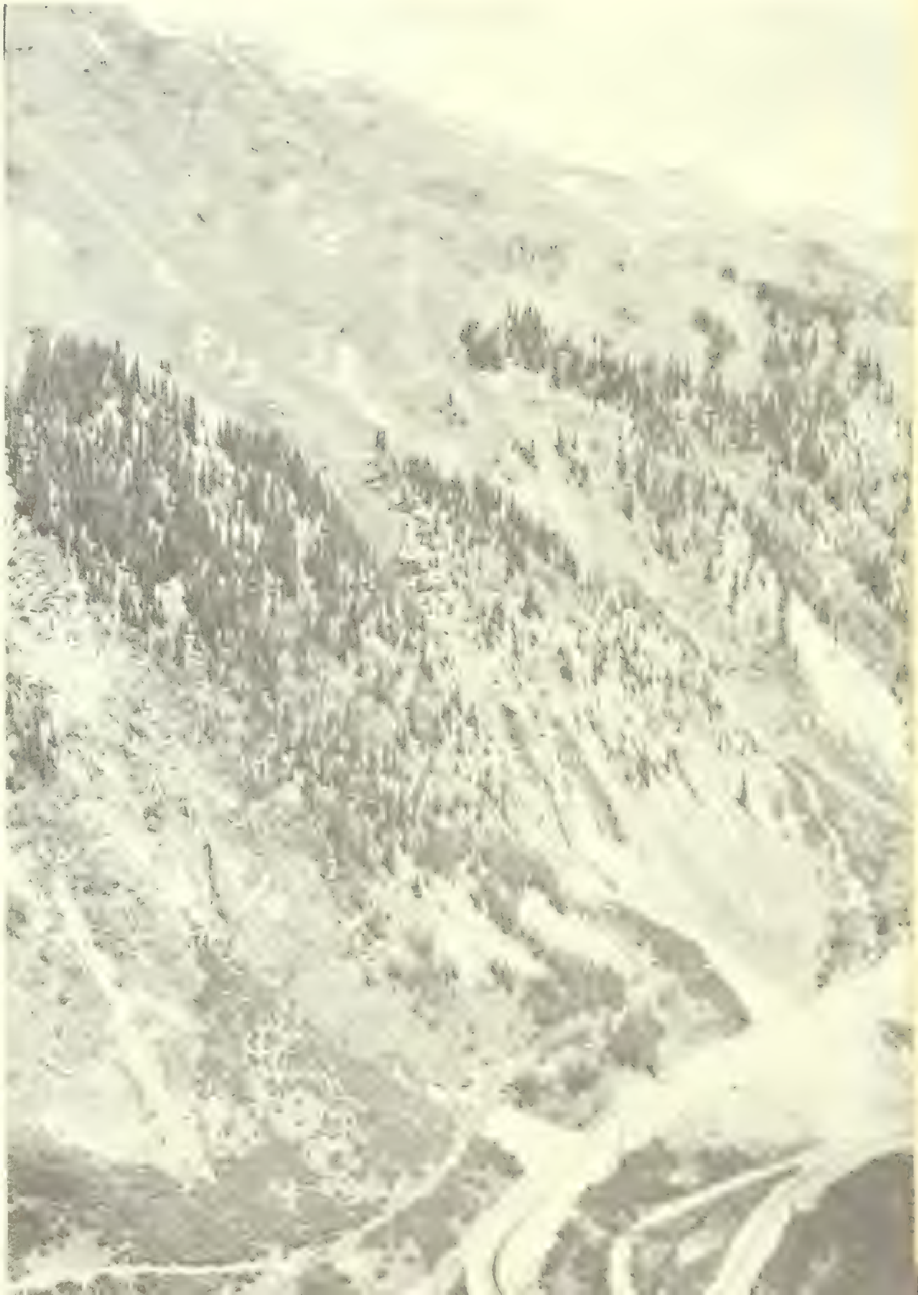
Highway No. 550 --
Red Mountain Pass
Photo: July 3, 1962

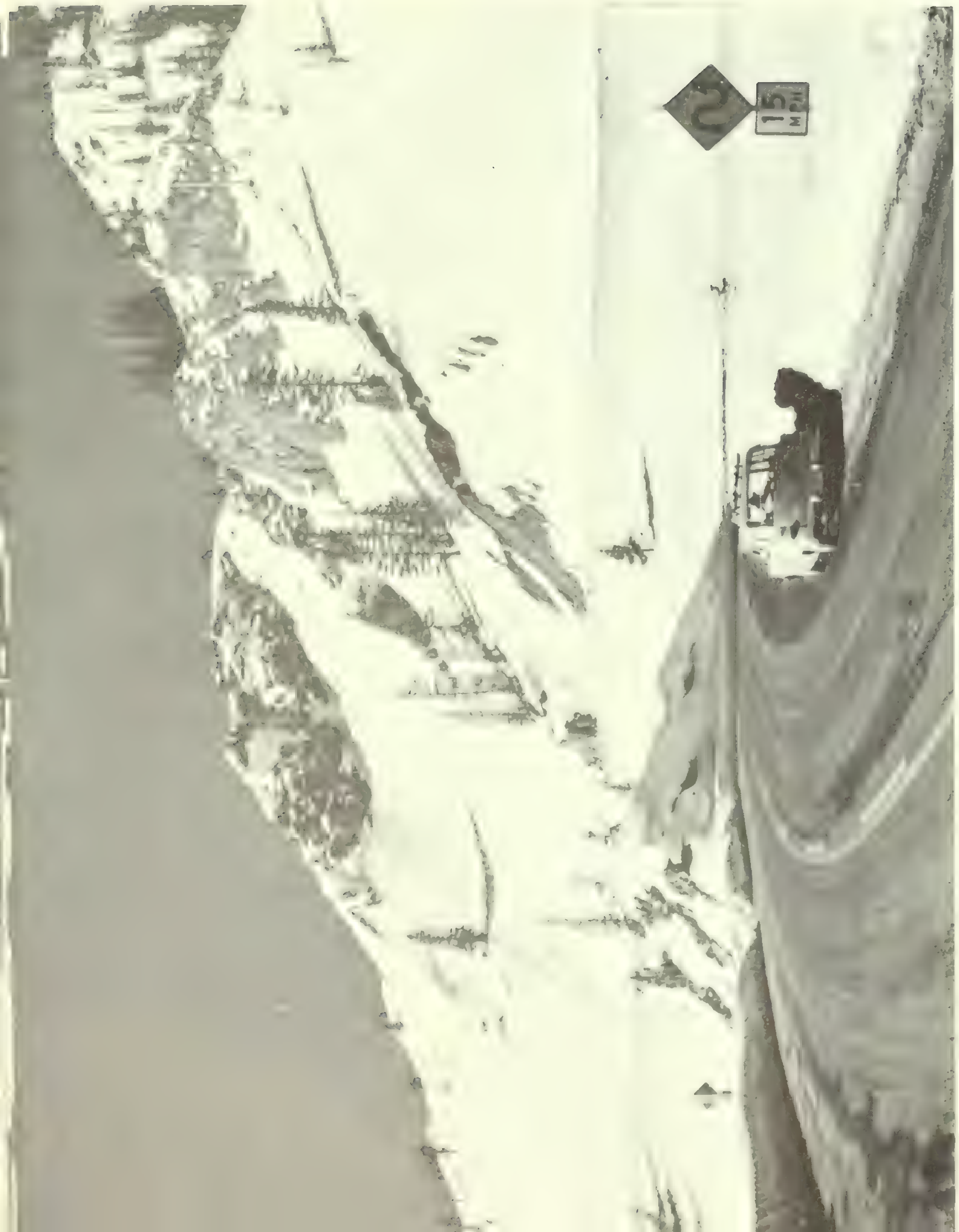
EAGLE (R-16)

LOCATION:
San Juan Mountains, Red Mountain Pass south; southeast slope of Bullion King Mountain.
CATCHMENT BASIN:
Bowl-shaped depressions on slope; above timberline; top is very steep and has some cliffs; 12,600-11,600 feet m.s.l.; 25 acres (10 ha).
TRACK:
Two gullylike depressions that join in lower section of track. Main track: vertical drop, 1,800 feet; length, 2,700 feet; average slope, 67 percent. Secondary track: vertical drop, 1,400 feet; length, 2,200 feet; average slope, 64 percent.
RUNOUT ZONE:
Alluvial fan; length, 1,300 feet; average slope, 34 percent. The lateral extent of runout zone is indefinite, but is at least 800 feet wide. Highway crosses this fan twice (both limbs of the switchback cross it).
CLASSIFICATION:
Medium-frequent.
POSSIBILITIES FOR STRUCTURAL CONTROL:
Extent and ruggedness of the catchment basin are unfavorable for use of supporting structures. Because the runout zone is very wide and crosses the highway twice, avalanche sheds would probably be no more economical than supporting structures.

PORCUPINE (R-17)

LOCATION:
San Juan Mountains, Red Mountain Pass south; southeast slope of Bullion King Mountain.
CATCHMENT BASIN:
Slight depression below prominent cliff; 11,900-11,700 feet m.s.l.; 4 acres (2 ha).
TRACK:
A narrow slot through scattered timber; vertical drop, 1,320 feet; length, 1,900 feet; average slope, 69 percent.
RUNOUT ZONE:
No transition above road. Natural runout zone is below upper road.
CLASSIFICATION:
Small-frequent.
POSSIBILITIES FOR STRUCTURAL CONTROL:
If the decision is made to control the Bullion King Mountain group of avalanches, this one can be handled with an avalanche shed.





Highway No. 550 --
Red Mountain Pass
Photo: January 3, 1962

BLUE POINT (R-18)

LOCATION:
San Juan Mountains, Red Mountain Pass north; east slope of Senator Ridge.

STARTING SPOT:
Hollow in scarp just above highway at an elevation of 11,000 feet m.s.l.; 2-1/2 acres (1 ha). It must be considered a bankslide rather than an avalanche, because the track has a length of only about 200 feet.

AVALANCHES:
Run to the road after almost every snowstorm.

CLASSIFICATION:
Small-frequent.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Snow nets are recommended. This is a good example of where supporting structures should be used.

Highway No. 550 --
Red Mountain Pass
Photo: January 3, 1962

WILLOW SWAMP (R-19)

LOCATION:
San Juan Mountains, Red Mountain Pass north; broken ground east of Senator Ridge just above the upper switchback of highway near Idarado Mine.

STARTING SPOTS:
In a deep hollow in slope; it might be head of an earth slip; below timberline; scattered trees; 11,400-11,100 feet m.s.l.; 7 acres (3 ha).

TRACK:
Short trough above highway; vertical drop, 600 feet; length, 1,200 feet; average slope, 50 percent.

RUNOUT ZONE:
On gentle section of slope where two switchbacks of highway lie.

AVALANCHES:
Crosses both limbs of the highway switchback.

CLASSIFICATION:
Small-frequent.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Control of starting spots with supporting structures and afforestation would be most economical. The few terraces and earth mounds that have been built in track would be a useful part of a larger, more comprehensive control project when one can be developed.

KING (R-20) (No photo)

LOCATION:
San Juan Mountains, Red Mountain Pass north; southeast-facing slope on a ridge between Spirit Gulch and Governor Gulch.

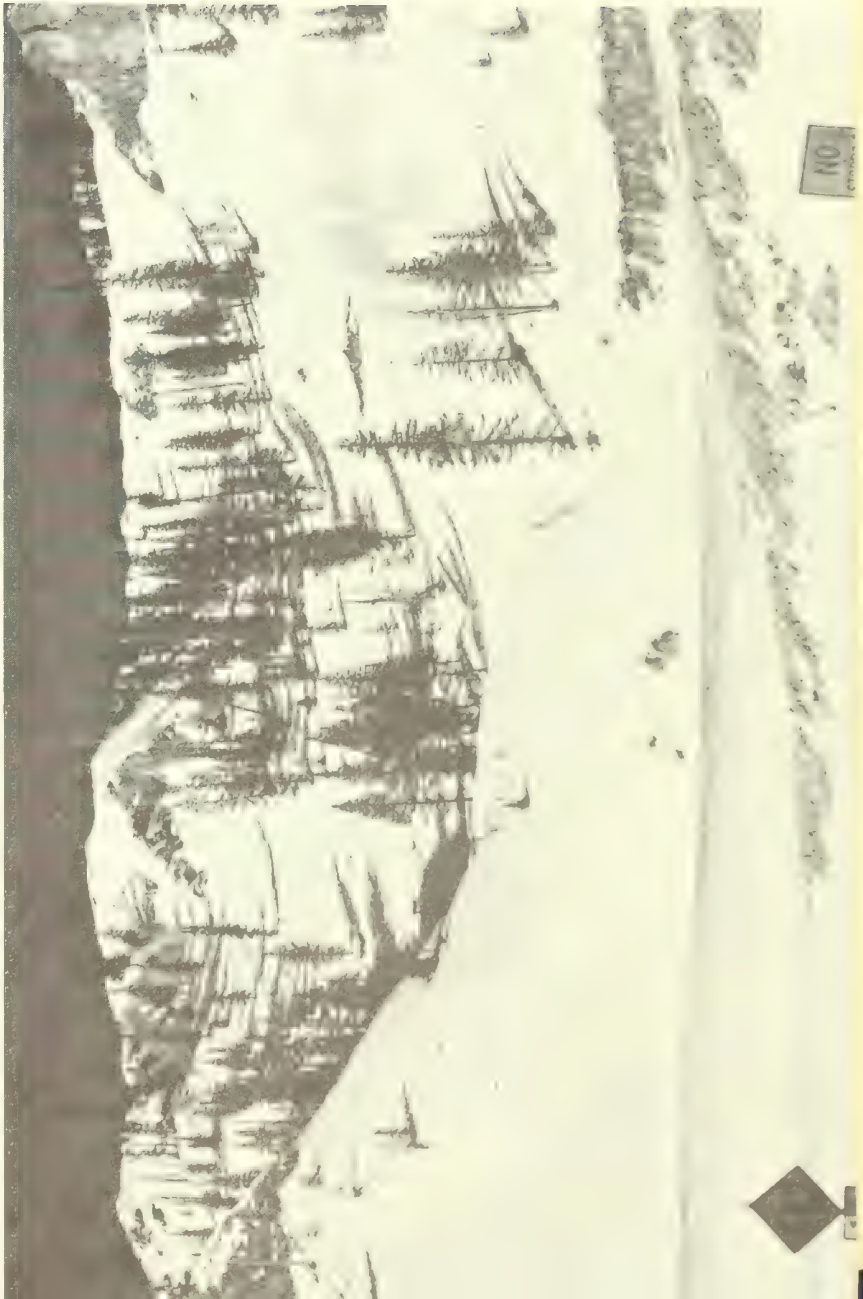
STARTING ZONE:
Uniform slope below timberline; 11,200-10,600 feet m.s.l.; 10 acres (4 ha).

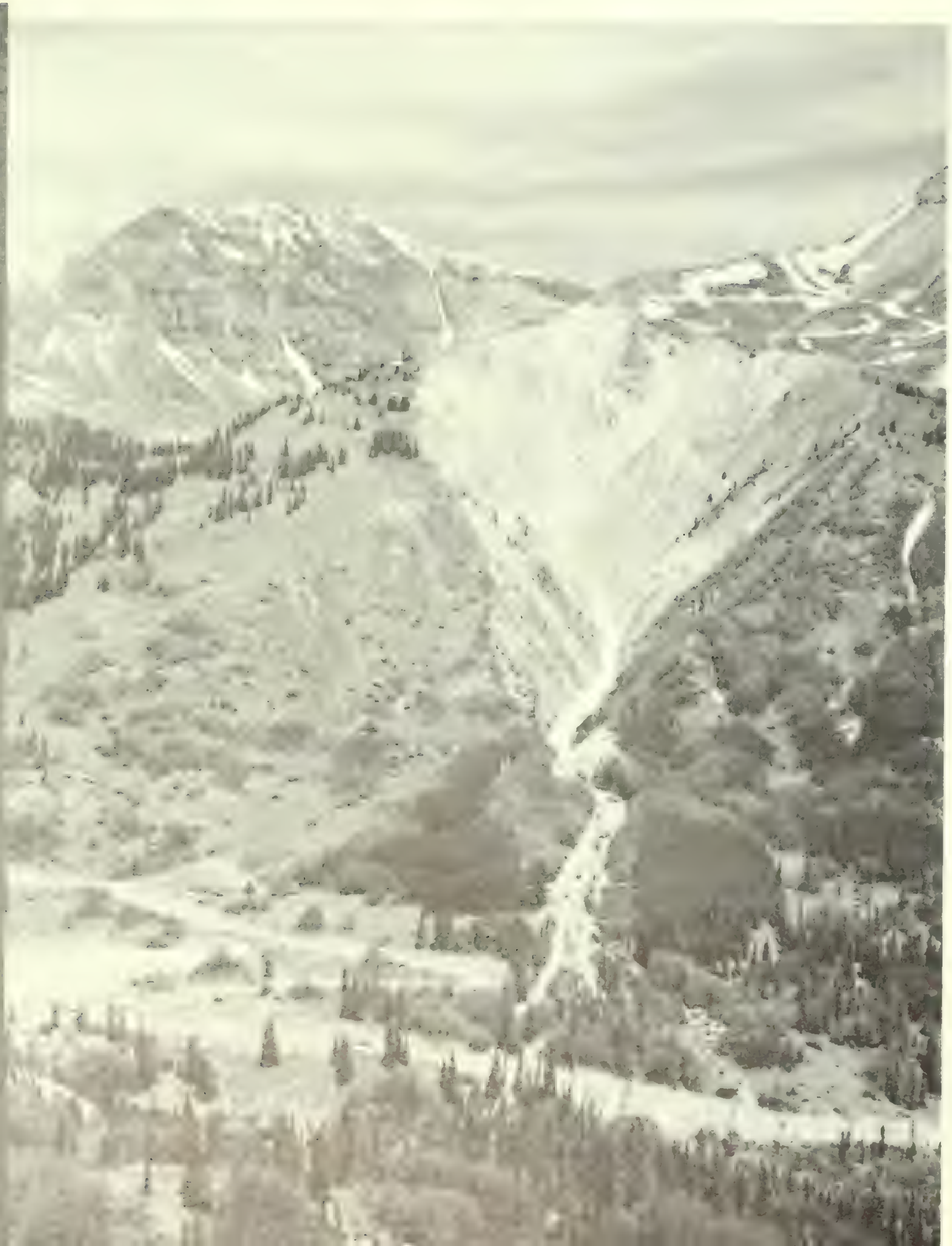
TRACK:
Indefinite; snow follows a slight depression in slope; vertical drop, 500 feet; length, 700 feet; average slope, 70 percent.

RUNOUT ZONE:
Lower, more gentle half of slope; length, 800 feet; average slope, 30 percent. Runout zone is indefinite, approximately 400 feet wide.

CLASSIFICATION:
Medium-occasional.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Control of starting zone by supporting structures and afforestation; diversion dam could also be used to reduce number of supporting structures.





Highway No. 550 --
Red Mountain Pass
Photo: July 2, 1962

GOVERNOR GULCH (R-21)

LOCATION:
San Juan Mountains, Red Mountain Pass north.

CATCHMENT BASIN:
Deep and well pronounced erosion hollow; 11,800-11,000 feet m.s.l. Highest part is just a little above timberline; very steep and rugged surface; 30 acres (12 ha).

TRACK:
Narrow, curved gully; vertical drop, 1,200 feet; length, 2,100 feet; average slope, 57 percent.

RUNOUT ZONE:
Alluvial fan of Governor Gulch; length, 2,100 feet; average slope, 21 percent.

CLASSIFICATION:
Medium-erratic.

POSSIBILITIES FOR STRUCTURAL CONTROL:
The erosion funnel of Governor Gulch gives more trouble with floods carrying boulders and mud to the highway than with avalanches, which occur very seldom. Structural control of the rugged catchment basin would be very difficult and expensive. The runout zone is long enough to plan diversion or retarding structures if necessary.

Highway No. 550 --
Red Mountain Pass
Photo: July 2, 1962

GALENA LION GULCH (R-22)

LOCATION:
San Juan Mountains, Red Mountain Pass north.

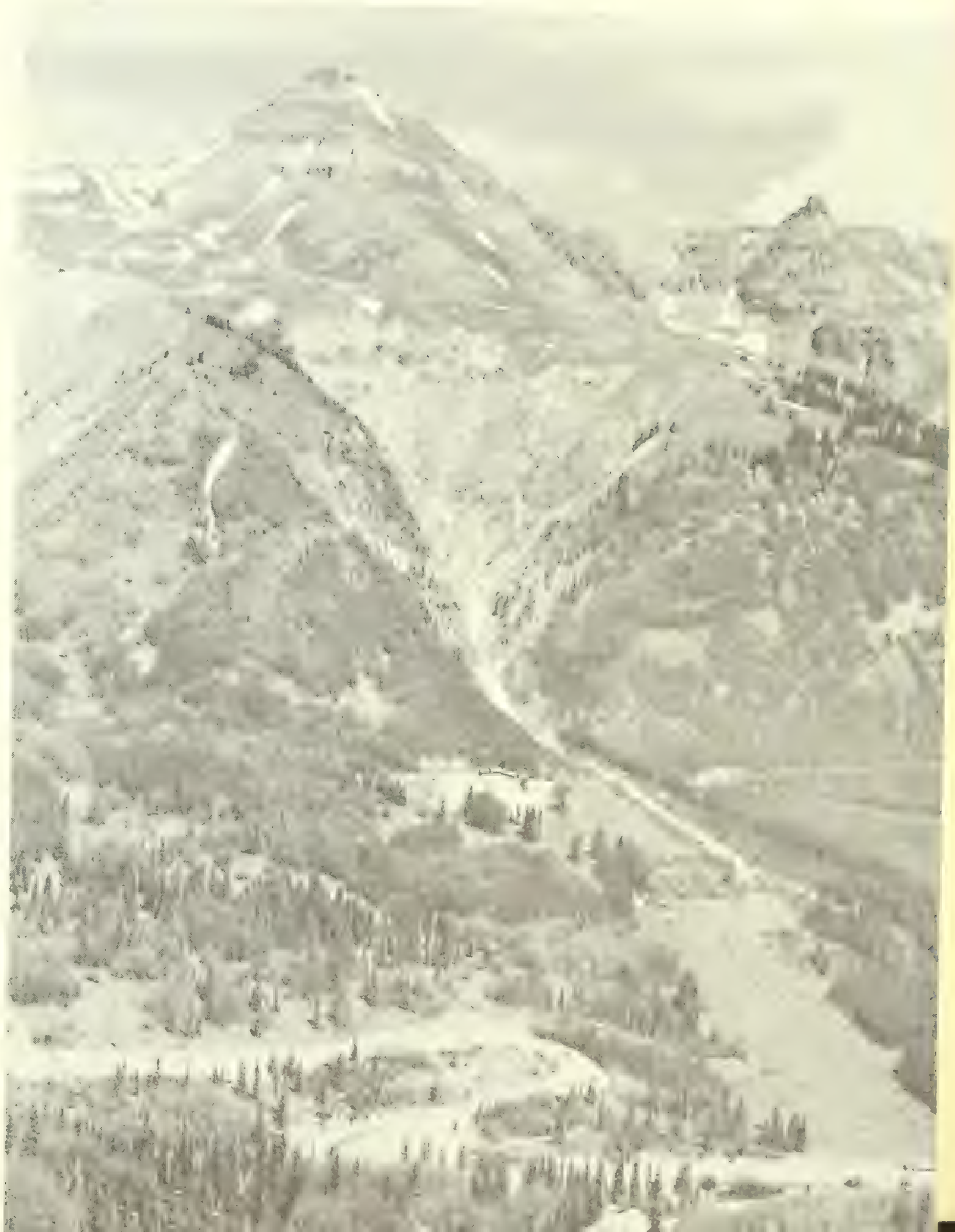
CATCHMENT BASIN:
Deep and well pronounced erosion hollow; highest point just a little above timberline; 11,700-10,600 feet m.s.l.; 32 acres (13 ha).

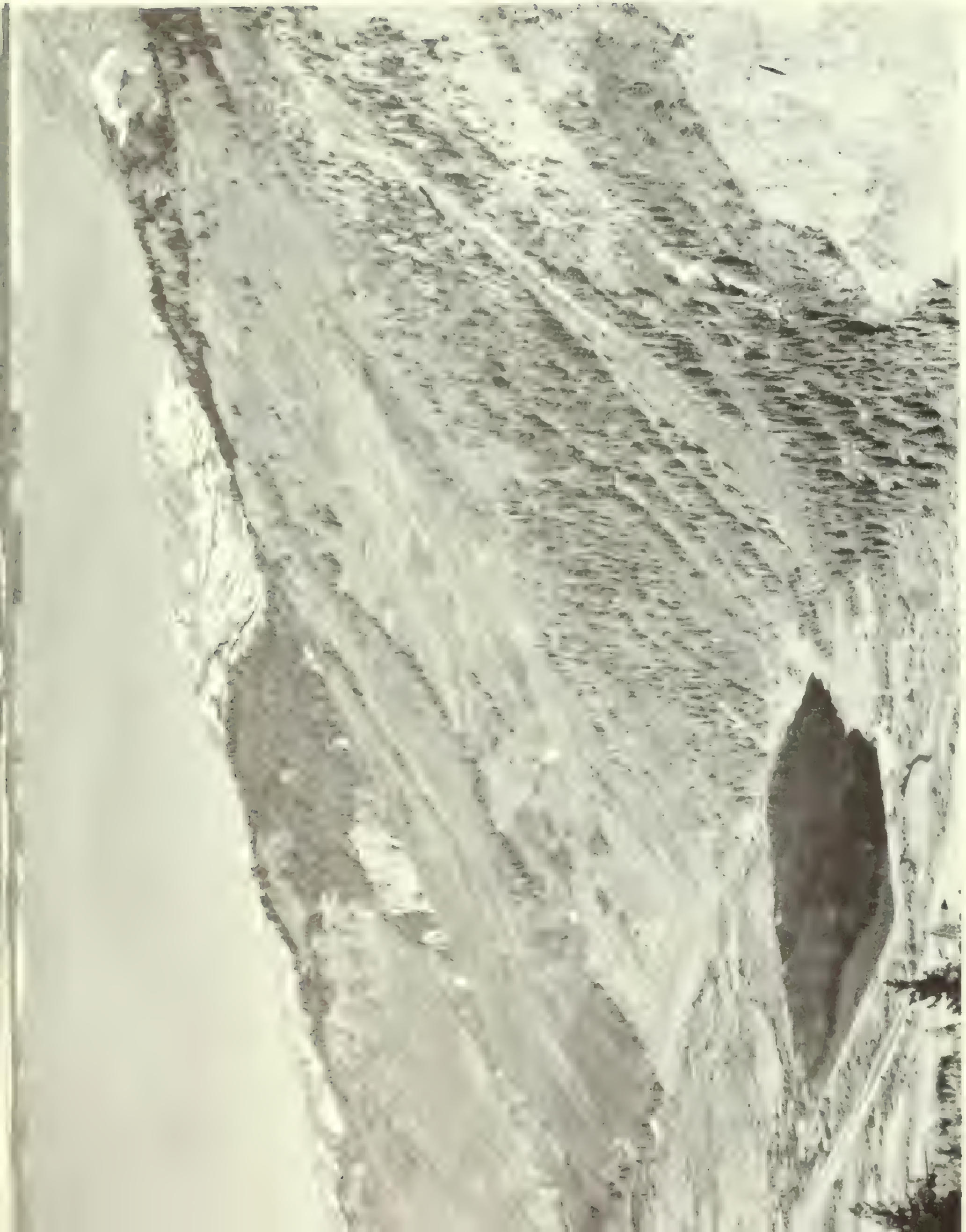
TRACK:
Narrow and curved gully; vertical drop, 1,100 feet; length, 2,100 feet; average slope, 52 percent.

RUNOUT ZONE:
Alluvial fan of Galena Lion Gulch; length, 2,300 feet; average slope, 23 percent.

CLASSIFICATION:
Large-erratic.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Since the runout zone is very gentle and long, avalanches seldom reach the highway. A cut in the aspen stand shows that in exceptional situations it does happen, however. If control is considered necessary, the terrain features are favorable for diversion structures.





Highway No. 550 --
Red Mountain Pass
Photo: July 3, 1962

IRONTON PARK (R-23)

LOCATION:
San Juan Mountains, Red Mountain Pass north; southeast slope of Hayden Mountain.

STARTING ZONE:
Wide, uniform slope below Half Moon Basin; below timberline; 11,300-10,600 feet m.s.l.; 60 acres (25 ha); starting zone is indefinite.

TRACK:
The entire slope; vertical drop, 1,640 feet; length, 2,800 feet; average slope, 60 percent.

RUNOUT ZONE:
Level bottom of Ironton Park; large avalanches have traveled over the flat ground to the highway--a distance of 1,200 feet.

AVALANCHES:
Avalanches of 1958 reached the road and crossed it.

CLASSIFICATION:
Large-erratic.

POSSIBILITIES FOR STRUCTURAL CONTROL:
The even slope, lying below timberline, would be favorable for supporting structures and afforestation. Because of the extent of the starting zone and the erratic behavior of the avalanche, however, such a control would not be economical. Another good possibility is a catchment dam in the flats of Ironton Park.

Highway No. 550 --
Red Mountain Pass
Photo: July 3, 1962

WEST GUADALUPE (R-24)

LOCATION:
San Juan Mountains, Red Mountain Pass north; east slope of Hayden Mountain.

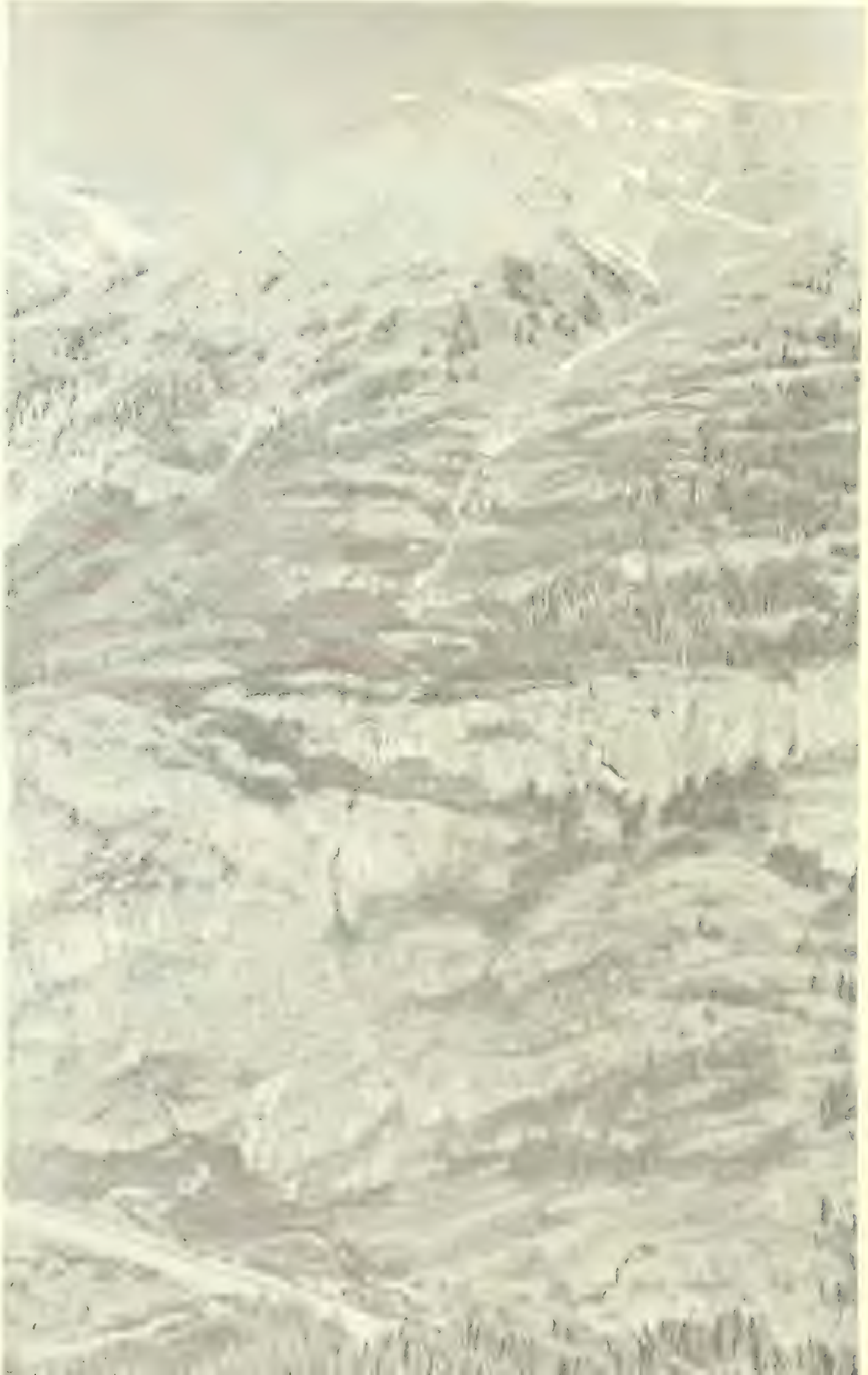
CATCHMENT BASIN:
Wide, rugged, bowl-shaped depression on the slope with cliffs; above timberline; 12,800-11,000 feet m.s.l.; 60 acres (25 ha).

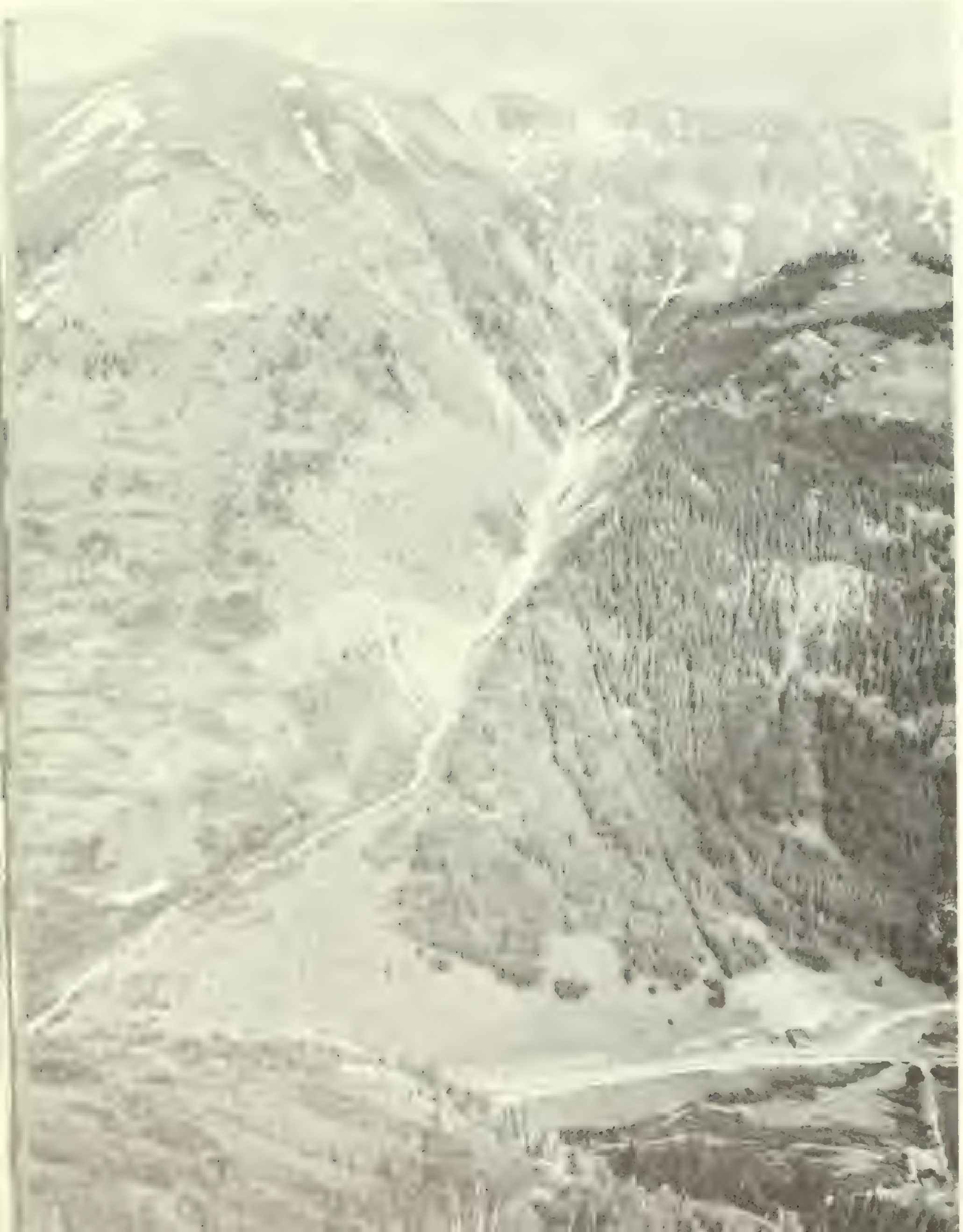
TRACK:
Few expressed depressions on the bedrock, cliffs, and terraces; vertical drop, 3,200 feet; length, 5,600 feet; average slope, 57 percent. A cliff 400 feet high immediately above highway; avalanches hit road with full speed.

RUNOUT ZONE:
Flat, alluvial bottom of Red Mountain Creek.

CLASSIFICATION:
Large-erratic.

POSSIBILITIES FOR STRUCTURAL CONTROL:
The only possible control is an avalanche shed, which would serve at the same time as protection against the EAST GUADALUPE avalanche.





Highway No. 550 --
Red Mountain Pass
Photo: July 2, 1962

EAST GUADALUPE (R-25)

LOCATION:
San Juan Mountains, Red Mountain Pass north; west slope of Abram's Mountain; Hendrick Gulch.

CATCHMENT BASIN:
Wide, steep, and rugged bowl-shaped depression on the slope; above timberline; 12,600-10,800 feet m.s.l.; 150 acres (60 ha).

TRACK:
Narrow ravine of Hendrick Gulch; vertical drop, 2,680 feet; length, 5,100 feet; average slope, 53 percent.

RUNOUT ZONE:
Wide alluvial fan of Hendrick Gulch; length, 1,600 feet; average slope, 20 percent; width of fan near highway, 1,000 feet.

AVALANCHES:
Run some place in the upper basin every year, but cross the road only when a large avalanche breaks loose.

CLASSIFICATION:
Large-erratic.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Supporting structures are out of the question because of extent and ruggedness of starting zone. Runout zone is favorable for a diversion dam. If protection is desired against both EAST GUADALUPE and WEST GUADALUPE avalanches, an avalanche shed would be the most economical solution.

Highway No. 550 --
Red Mountain Pass
Photo: March 24, 1962

SLIPPERY JIM (R-26)

LOCATION:
San Juan Mountains, Red Mountain Pass north; west slope of Abram's Mountain.

STARTING ZONE:
Indefinite, irregular, rocky slope with many terraces and little cliffs; light stands of aspen and spruce; 11,600-10,000 feet m.s.l.; 37 acres (15 ha).

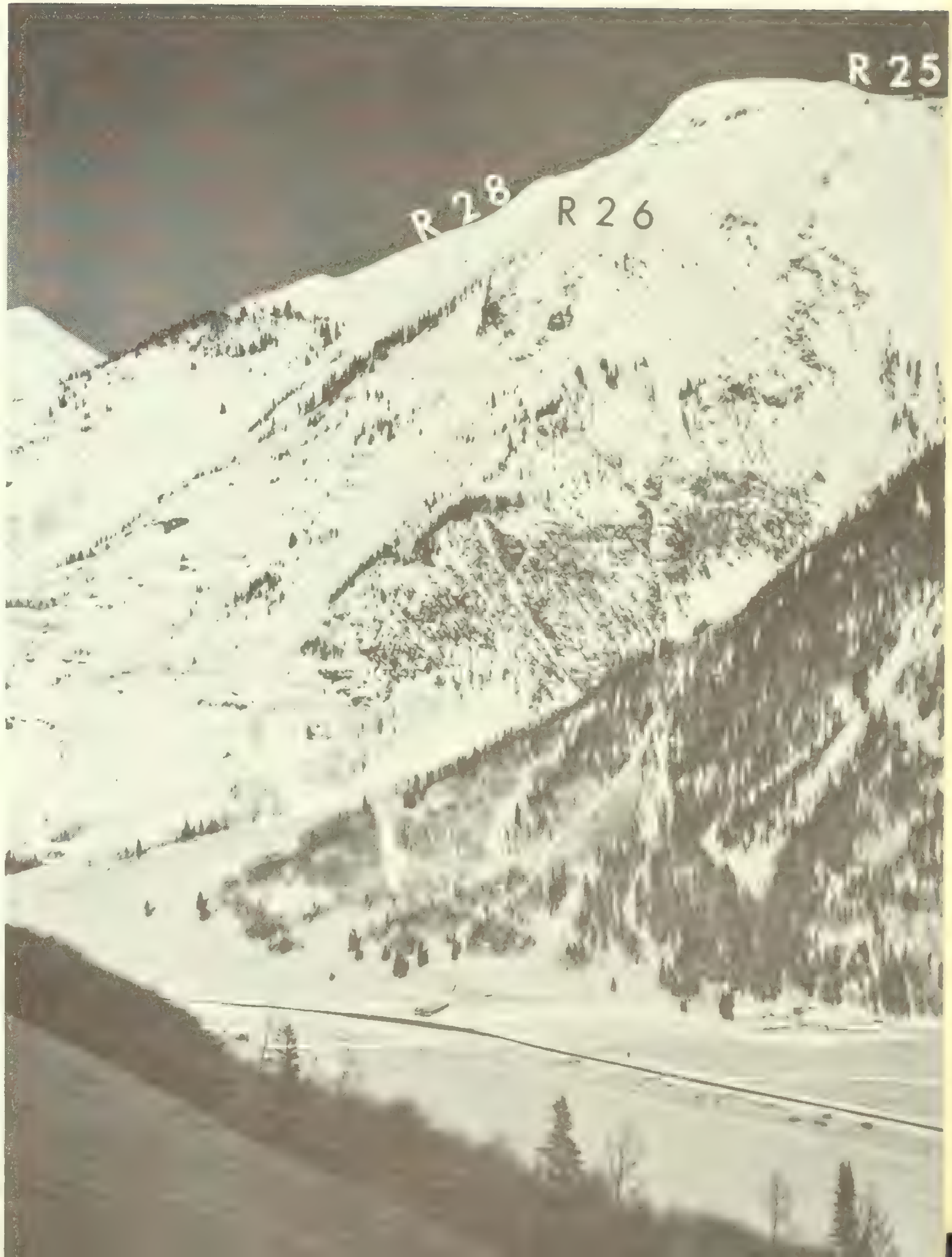
TRACK:
Very wide; indefinite; whole width of the slope can run; longitudinal profile is irregular; flat sections alternate with little cliffs; vertical drop, 2,000 feet; length, 2,800 feet; average slope, 70 percent.

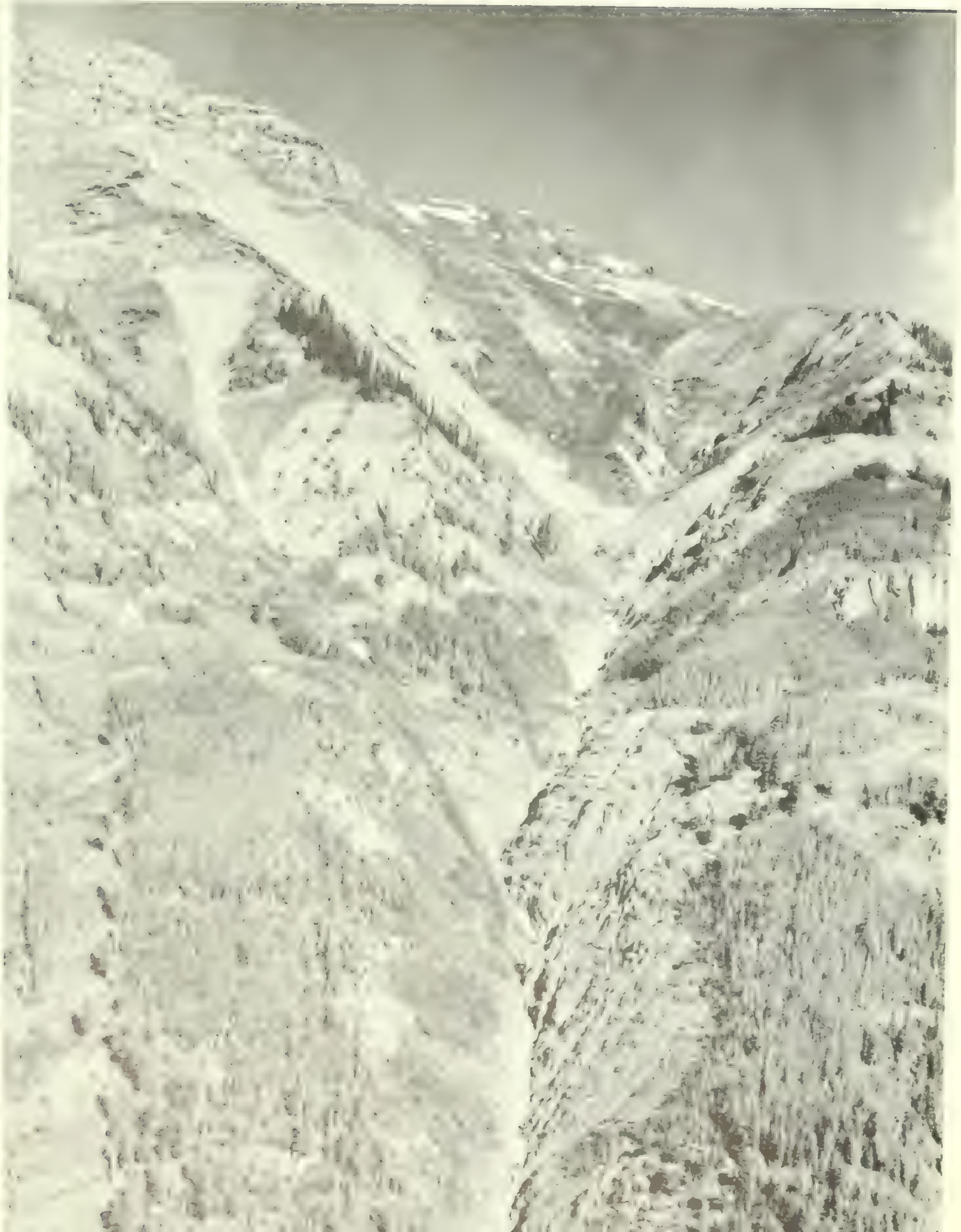
RUNOUT ZONE:
There is only a short transition zone above the highway with a length of 200 feet; average slope, 40 percent. The avalanche crosses the upper portion of the switchback of the highway in two places.

AVALANCHES:
Very bad, from the standpoint of the highway. It has run to the road at least 5 times in the past 10 years.

CLASSIFICATION:
Large-frequent.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Control of the starting zone is possible. However, considering neighboring avalanches (EAST and WEST RIVERSIDE) the simplest solution would be a tunnel.





Highway No. 550 --
Red Mountain Pass
Photo: July 3, 1962

WEST RIVERSIDE (R-27)

LOCATION:
San Juan Mountains, Red Mountain Pass north; east slope of Hayden Mountain.

CATCHMENT BASIN:
A large, irregular and rocky basin with very steep spots; above timberline; 11,800-10,200 feet m.s.l.; 150 acres (60 ha).

TRACK:
Narrow, steep, and curved gully; vertical drop, 2,480 feet; length, 4,700 feet; average slope, 53 percent.

RUNOUT ZONE:
Track ends in bottom of Red Mountain Creek gorge without a transition zone. Highway lies 50 feet up on opposite slope. Dust avalanches that hit the bottom with full speed will climb up the opposite slope and reach the highway. This is especially true for the avalanche blast.

AVALANCHES:
The EAST RIVERSIDE and WEST RIVERSIDE avalanches hit the highway from opposite sides. It is not uncommon for both slides to run at the same time. WEST RIVERSIDE has run to the road at least 7 times in the past 10 years.

CLASSIFICATION:
Large-frequent.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Heavy avalanche shed or tunnel to protect the highway from both WEST and EAST RIVERSIDE.

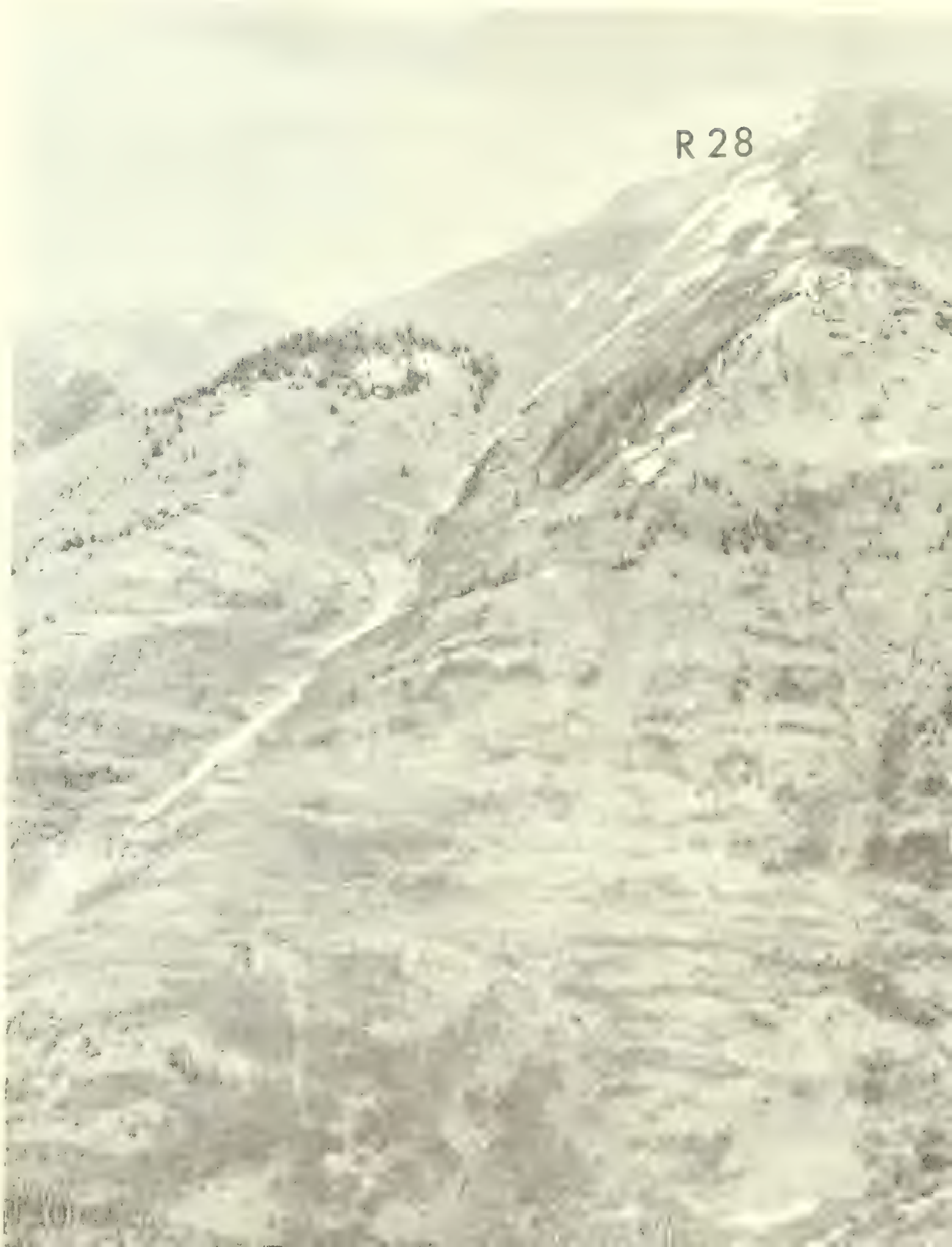
Highway No. 550 --
Red Mountain Pass
Photo: July 2, 1962

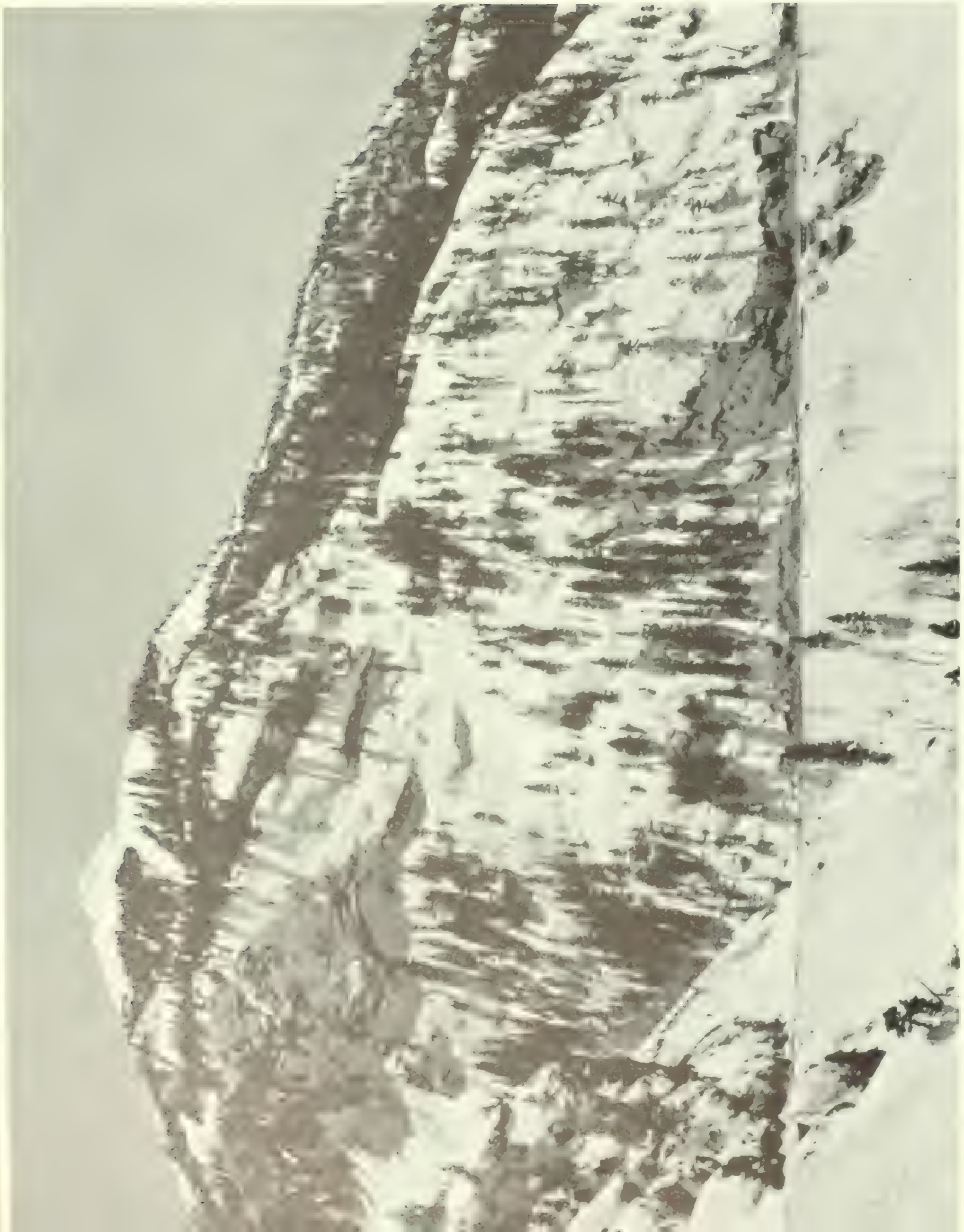
EAST RIVERSIDE (R-28)

LOCATION:
San Juan Mountains, Red Mountain Pass north; northwest slope of Abram's Mountain.
CATCHMENT BASIN:
Bowl-shaped depression in the slope; above timberline; 12,600-10,800 feet m.s.l.; 75 acres (30 ha).
TRACK:
Steep, rocky gully of Curran Gulch; vertical drop, 3,200 feet; length, 5,100 feet; average slope, 63 percent; avalanches hit highway directly.
RUNOUT ZONE:
Bottom of Uncompahgre Gorge below the road.
AVALANCHES:
A very bad avalanche that has run over the road at least 25 times in the past 10 years.
CLASSIFICATION:
Large-frequent.
POSSIBILITIES FOR STRUCTURAL CONTROL:
Tunnel or a heavy avalanche shed.

DUNSMORE (R-29) (No photo)

LOCATION:
San Juan Mountains, Red Mountain Pass north; on opposite slope of Silver Gulch in Uncompahgre Gorge.
STARTING SPOTS:
Indefinite; in the cliffs (bedrock) with scattered trees; elevation about 9,400 feet m.s.l.; approx. 2 acres (1 ha).
TRACK:
Indefinite; slides fall down off the cliffs.
CLASSIFICATION:
Small-occasional.
POSSIBILITIES FOR STRUCTURAL CONTROL:
Starting spots must be examined in more detail before any suggestions can be made. Since the starting zone is very rugged an avalanche shed seems the most logical structural defense.





Highway No. 550 --
Red Mountain Pass
Photo: March 25, 1962

MOTHER CLINE (R-30)

LOCATION:
San Juan Mountains, Red Mountain Pass north; in Uncompahgre Gorge, one-third mile above the junction of Red Mountain Creek and Uncompahgre River.

STARTING ZONE:
Just a little above highway on bare, rock slabs. Sparsely timbered; 9,800-9,000 feet m.s.l.; 10 acres (4 ha).

TRACK:
Indefinite; vertical drop, 400 feet; length, 800 feet; average slope, 50 percent.

RUNOUT ZONE:
Slide crosses highway, and runs down into Red Mountain Creek Gorge.

AVALANCHES:
Has run over the road at least 21 times in past 10 years. Often runs in spring when melt water forms ice over rocks.

CLASSIFICATION:
Medium-frequent.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Supporting structures in starting zone are possible. Good rock would permit snow nets. Another possibility is an avalanche shed.

Highway No. 550 --
Red Mountain Pass
No photo

SILVER POINT (R-31)

LOCATION:
San Juan Mountains, Red Mountain Pass north; Uncompahgre Gorge between Uncompahgre River Tunnel and Bear Creek Falls.

STARTING ZONE:
West-facing rock walls of Uncompahgre Gorge; 10,200-9,400 feet m.s.l.; 5 acres (2 ha).

TRACK:
Very steep couloir in the rock wall. Avalanches strike highway directly; vertical drop, 1,500 feet; length, 1,600 feet; average slope, 94 percent.

RUNOUT ZONE:
None; snow masses do not run, but literally fall off the rock walls.

CLASSIFICATION:
Small-occasional.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Starting spots cannot be controlled economically; best control is an avalanche and rock fall shed.

Highway No. 550 --
Red Mountain Pass
No photo

JACKPOT (R-32)

LOCATION:
San Juan Mountains, Red Mountain Pass north, between Bear Creek Trail Tunnel and Ouray.

STARTING SPOTS:
At foot of high rock wall at an elevation of 9,000 feet m.s.l. in an opening in the timber; 2 acres (1 ha).

TRACK:
Small slot in the timber running down to strike the highway directly; vertical drop, 600 feet; length, 900 feet; average slope, 67 percent.

RUNOUT ZONE:
Bottom of Uncompahgre Gorge.

CLASSIFICATION:
Small-occasional.

POSSIBILITIES FOR STRUCTURAL CONTROL:
Supporting structures in the starting spots, with afforestation.

Agriculture --- CSU, Ft Collins

Frutiger, Hans.
1964. Snow avalanches along Colorado mountain highways.
U. S. Forest Serv. Res. Paper RM-7, 85 pp., illus. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Describes and illustrates characteristics of 80 avalanches along four highways in the Colorado mountains; discusses possibilities for structural control. The avalanches -- in Loveland Pass, Berthoud Pass, Wolf Creek Pass, Coal Bank Hill, Molas Divide, and Red Mountain Pass -- are located on topographic maps.

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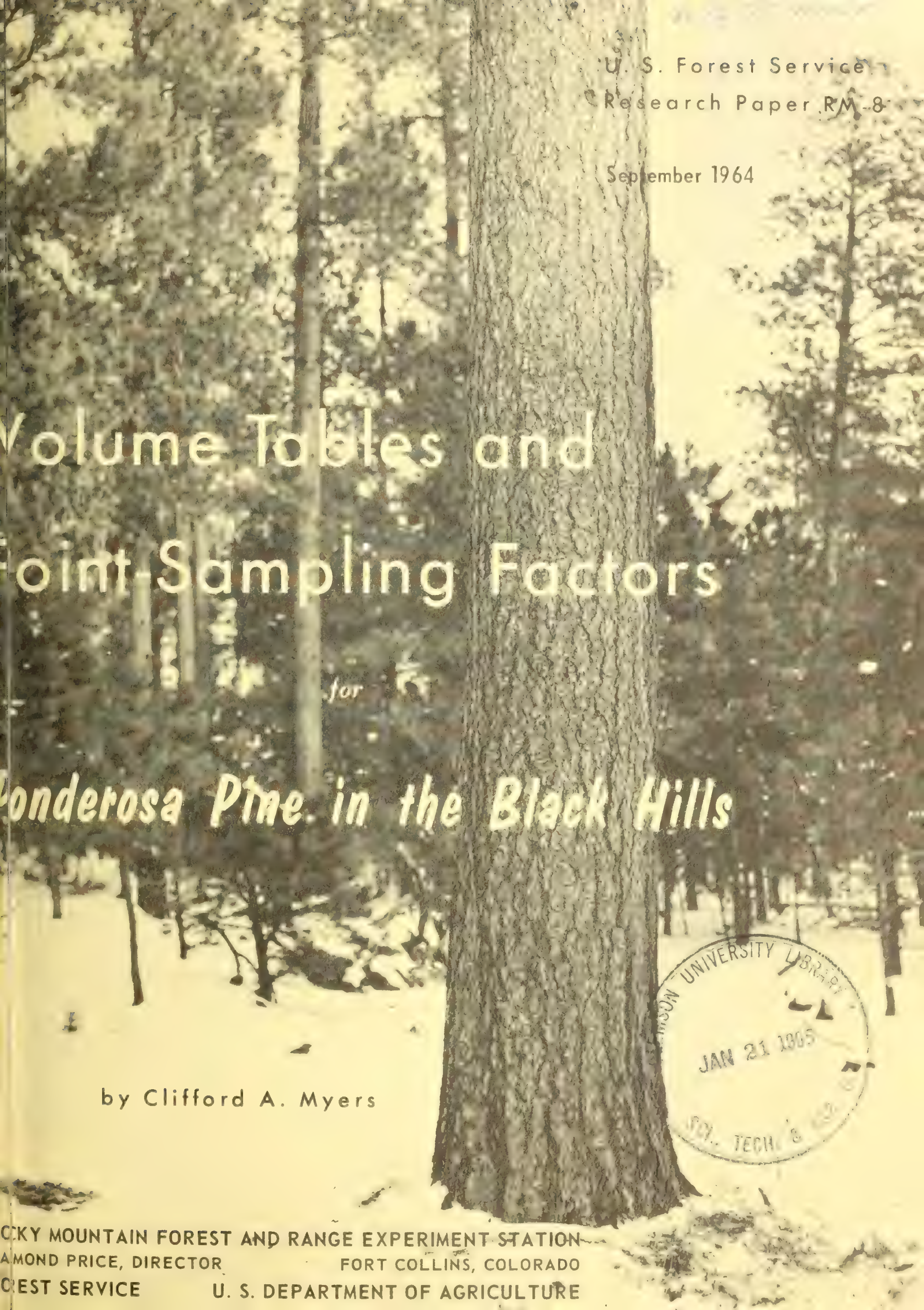

U. S. Forest Service
Research Paper RM-8

September 1964

Volume Tables and oint Sampling Factors

for

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by Clifford A. Myers

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By

Clifford A. Myers, Research Forester
Rocky Mountain Forest and Range Experiment Station[1]

Central headquarters maintained in cooperation with Colorado State University at ort Collins.

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Volume Tables and Point-Sampling Factors for Ponderosa Pine in the Black Hills

By

Clifford A. Myers

INTRODUCTION

The tables presented here give values needed to determine the volumes of ponderosa pine (Pinus ponderosa Laws.) in the Black Hills of South Dakota and Wyoming. They provide timber cruisers and growth estimators with the following:

1. Gross volumes in total and merchantable cubic feet.
2. Gross volumes in board feet, International 1/4-inch and Scribner log rules.
3. Point-sampling factors for merchantable cubic feet and board feet.
4. Distribution of board foot volume among the logs of a tree.

Volume on an area may be determined from: (1) measurements of tree diameters and heights, (2) measurements of diameters and of sufficient heights to convert the appropriate volume tables to local volume tables (Chapman and Meyer, 1949), or (3) tree counts obtained by point-sampling.

Sample trees were measured in all areas of commercial ponderosa pine in the Black Hills of South Dakota and Wyoming and the Bear Lodge Mountains of Wyoming.

DEFINITIONS AND STANDARDS

Variables used in the tables, and standards followed in field measurement and computations, are defined as follows:

Diameter breast high (d.b.h.).--Measured to 0.1 inch outside bark 4.5 feet above ground level.[2] Full-inch diameter classes, with class midpoints at the half-inch marks, were used in the tables (12.5, 13.5, etc.).

Scaling diameter of logs.--Average diameter inside bark to 0.1 inch, measured at the upper (small) end of logs or half-logs. Saw-log diameter classes followed conventional scaling practice, with the class midpoints at whole inches (8.0, 9.0, etc.).

Minimum top diameter of sawtimber trees.--Diameter inside bark 8 inches, which conforms to usual practice in the Black Hills. Logs with a scaling diameter less than 7.6 inches (8-inch class) usually were not included in saw-log volume. A few logs with a scaling diameter of 7 inches were included to satisfy requirements of the 4-foot rule described with the definition of height in logs, below. This also conforms to local practice.

Total height.--Measured to the nearest foot from ground level at the tree base upward to the tip. Forked, stag-topped, or other deformed trees were not included in the sample. Midpoints of the total height classes used in the tables were multiples of 10.0 feet, as 10.0, 20.0, etc.

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[2] *Half the heights were measured from average ground level and half from the uphill side of the tree. Variations in positions of d.b.h. and scaling diameters were too small to make significant differences in volumes.*

Height in logs.--Measured from the top of a stump 1.0 foot high upward to the limit of saw log utilization. Each tree was divided into as many standard 16.3-foot-long logs as possible. An additional half-log, if present, was taken from the uppermost part of the merchantable length. Portions of the bole above the height of minimum top saw-log diameter were included in the uppermost saw log if the standard length of the log or half-log ended within 4.0 feet above this height. This "4-foot rule" was used to avoid biased negative error in volume (Chapman and Meyer, 1949).

EXPLANATION OF TABLES

The general definitions and standards given apply to all tables. Explanation of each type of table and suggestions for use are presented here.

Volume Tables

Headings and footnotes with each volume table (tables 1, 2, 4, 6, 8, 10) give the volume unit, type of height measurement, utilization standards, and volume equations used in its compilation. Ten-foot or half-log height classes and full-inch diameter classes were used in all tables.

The volume tables were derived from linear regressions in V and D^2H, of the form:
$V = a + b\ D^2H$,
where:
V = gross volume in the appropriate unit
D = diameter breast high outside bark
H = total height in feet or in standard logs and half-logs
a,b = regression constants

Two equations were used to derive each table; the relationship between V and D^2H could not be expressed by a single linear regression over the full range of the basic data. Correlation coefficients (r) of the 12 volume equations ranged from 0.891 (board feet with total height, small trees) to 0.993 (total cubic feet).

The number of logs in a tree shown in the tables is not necessarily the number that will actually be cut from it. Instead, it is the number of logs between the stump and the height where minimum top diameter is reached. To locate the minimum top, the 4-foot rule explained under the heading "height in logs" should be used.

Volume of nonmerchantable logs below the height of minimum top diameter should be deducted by estimation of scaling diameters, use of taper tables, or according to the percentages in table 13. Volume must not be reduced by tallying fewer logs in the tree. For example, assume that a sound tree 18 inches in diameter has a bole length of 65.2 feet (4 logs) between the stump and the height where diameter inside bark is 8 inches. The tree has a gross volume of 372 board feet Scribner Rule (table 6). The top log is too limby to send to the sawmill. This log contains 9 percent of the board feet in the tree (table 13) and the other logs contain 91 percent. When 9 percent or 33 board feet is deducted, the tree contains 339 board feet. If the tree were tallied as an 18-inch, 3-log tree, it would be incorrectly credited with a volume of 273 board feet.

Point-Sampling Factors

The first five tables of point-sampling factors (tables 3, 5, 7, 9, 11) give the factors for each of numerous combinations of tree diameter and height. Volumes per square foot of basal area were obtained from the equations in the table footnotes. These equations resulted from the division of each volume equation (tables 2, 4, 6, 8, 10) by $0.005454\ D^2$, a formula for basal area (B).

Table 12 was derived from the other tables of point-sampling factors. The factor for each height class is the weighted average of the factors in that class given in table 2, 4, 6, 8, or 10. Weights were obtained from random samples of heights and diameters in all areas of commercial ponderosa pine in the Black Hills.

Point-sample cruising for volume can be done in several ways: (1) Diameters and heights of trees counted through the prism or relascope may be measured, (2) diameters may be estimated and heights measured, or (3) heights of the counted trees may be measured and no record made of tree diameters. The procedure selected will depend on the accuracy desired (relative accuracy usually in the order listed above) and the time and personnel available for the job. Point-sampling factors are provided for each alternative.

The diameter and height of each counted tree may be measured and a volume conversion factor selected for each combination of diameter and height (tables 3, 5, 7, 9, 11). Volume per acre is computed as follows:

1. Multiply the number of counted trees in each diameter-height class by the point-sampling factor for the class.
2. Total the products of step one.
3. Multiply this total by the basal area factor of the prism or other angle gauge used.
4. Divide the product of step three by the number of points sampled on the tract.

Time can often be saved if the heights of the counted trees are measured while diameters are estimated and tallied by broad diameter classes. Inspection of the tables shows that volumes per square foot of basal area often do not differ greatly among trees of a single height class. For example the merchantable volumes of trees 70 feet tall vary from 26.1 to 30.3 cubic feet per square foot as diameter increases from 7 to 27 inches (table 3). Board feet per square foot of basal area changes little with diameter when tree heights are measured in logs (tables 7, 11). Therefore, the increased time spent measuring diameters may not materially increase accuracy.

Measurement of heights with no record made of diameters is recommended when there is little change in volumes per square foot within a height class. Point-sampling factors in table 12, based on height only, will be most useful where the distributions of diameters within height classes approximate those used in preparation of the tables. Differences in the relationship between height and diameter due to differences in site quality or stand density may change the factor for each height class. These changes may be accounted for by computing new factors for each height class, using tables 3, 5, 7, 9, or 11 and almost the same procedure used to derive a local volume table from a standard table (Chapman and Meyer, 1949). Diameters are plotted over heights, since height will be retained as the measured variable.

The techniques of point sampling have been described in numerous publications. A good discussion of the method was presented by Bonnett (1959). Allen and Mogren (1960) described a simple procedure for determining the number of sampling points, and Afanasiev (1958) listed precautions on the use of point-sampling on small tracts. Basic American references were prepared by Grosenbaugh (1952, 1955, 1958).

Percentage of Tree Board-Foot Volume in Each Log

The board-foot volume in each log-quality class or the volume in cull logs can be determined with the percentages from table 13. Each line in the body of the table gives the distribution of volume among the logs of a tree of specified diameter and merchantable length. For example, in 18-inch, 3-log trees, the butt log contains 53 percent of the board feet, the middle log contains 34 percent, and the top log 13 percent.

Percentages for diameters that are not included in table 13 can be obtained by interpolation.

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*Address requests for copies to the originating office.

Table 1.--Gross volumes of entire stem in cubic feet, ponderosa pines in the Black Hills of South Dakota and Wyoming

Cubic feet inside bark

Entire stem including stump and top

Total height above ground

Diameter breast height outside bark (Inches)	Total height in feet											Basis: Trees
	10	20	30	40	50	60	70	80	90	100	110	
	Volume in cubic feet											
1	0.08	0.13	0.18									1
2	0.17	0.31	0.45	0.58								13
3	0.30	0.57	0.84	1.11	1.39							22
4	0.48	0.93	1.37	1.82	2.27							25
5		1.37	2.04	2.71	3.38							26
6		1.90	2.84	3.77	4.71	5.64						25
7		2.52	3.76	5.01	6.25	7.50	8.74					30
8		3.23	4.83	6.43	8.02	9.62	11.2					30
9		4.02	6.02	8.02	10.0	12.0	14.1	16.3				29
10			7.35	9.79	12.2	14.8	17.5	20.3				29
11			8.81	11.7	14.8	18.1	21.3	24.6	27.9			36
12			10.4	13.9	17.8	21.6	25.5	29.4	33.2			35
13			12.1	16.5	21.0	25.5	30.0	34.5	39.0			43
14				19.2	24.5	29.7	34.9	40.1	45.3	50.5		28
15				22.2	28.2	34.1	40.0	46.0	51.9	57.9		36
16				25.4	32.1	38.9	45.6	52.3	59.1	65.8		20
17					36.3	43.9	51.5	59.1	66.6	74.2		15
18					40.8	49.2	57.7	66.2	74.6	83.1	91.6	12
19					45.5	54.9	64.3	73.7	83.1	92.5	102	12
20					50.4	60.8	71.2	81.6	92.0	102	113	8
21						67.1	78.5	89.9	101	113	124	7
22						73.6	86.1	98.6	111	124	136	3
23						80.4	94.1	108	121	135	149	3
24						87.5	102	117	132	147	162	4
25						95.0	111	127	143	159	175	1
26						103	120	137	155	172	190	2
27						111	129	148	167	186	204	2
Basis: No. trees	5	35	62	52	80	84	92	52	26	9	0	497

Block indicates extent of basic data.

Derived from: $V = 0.002213\ D^2H + 0.030288$, for D^2H to 6,000

$V = 0.002474\ D^2H - 1.557103$, for D^2H larger than 6,000

Standard errors of estimate: ± 9.04 percent; ± 11.63 percent

Diameter classes full-inch; e. g. 20-inch class includes 20.0 to 20.9

Table 2.--Gross merchantable volumes in cubic feet to a 4.0-inch top, ponderosa pines in the Black Hills of South Dakota and Wyoming

Cubic feet inside bark
Merchantable stem excluding stump and top

Top diameter 4.0 inches inside bark
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Total height in feet										Basis: Trees
	20	30	40	50	60	70	80	90	100	110	
	Volume in cubic feet										
5	0.36	1.05	1.75	2.44							26
6	0.91	1.88	2.85	3.82	4.79						25
7	1.55	2.84	4.14	5.43	6.72	8.01					30
8	2.29	3.95	5.61	7.27	8.93	10.6					30
9	3.11	5.19	7.26	9.33	11.4	13.5	15.1				29
10		6.57	9.10	11.6	14.2	16.3	19.0				29
11		8.08	11.1	14.2	16.8	20.0	23.2	26.4			36
12		9.73	13.3	16.5	20.3	24.1	27.8	31.6			35
13		11.5	15.3	19.7	24.1	28.4	32.8	37.2			43
14			18.0	23.0	28.1	33.2	38.2	43.3	48.3		28
15			20.9	26.7	32.4	38.2	44.0	49.8	55.6		36
16			24.0	30.5	37.1	43.6	50.2	56.7	63.3		20
17				34.6	42.0	49.3	56.7	64.1	71.5		15
18				38.9	47.2	55.4	63.6	71.9	80.1	88.4	12
19				43.5	52.7	61.8	71.0	80.1	89.3	98.4	12
20				48.3	58.4	68.6	78.7	88.8	98.9	109	8
21					64.5	75.6	86.8	97.9	109	120	7
22					70.9	83.0	95.2	107	120	132	3
23					77.5	90.8	104	117	131	144	3
24					84.4	98.9	113	128	142	157	4
25					91.7	107	123	139	154	170	1
26					99.2	116	133	150	167	184	2
27					107	125	143	162	180	198	2
Basis: No. trees	3	41	49	80	84	92	52	26	9	0	436

Block indicates extent of basic data.
Derived from $V = 0.002297\ D^2H - 1.032297$ for D^2H to 6,700
$V = 0.002407\ D^2H - 2.257724$ for D^2H larger than 6,700
Standard errors of estimate: ± 12.03 percent; ± 12.09 percent
Diameter classes full-inch; e.g. 20-inch class includes 20.0 to 20.9

Table 3.--Gross merchantable volumes in cubic feet per square foot of basal area, ponderosa pines in the Black Hills of South Dakota and Wyoming

Cubic feet inside bark
Merchantable stem excluding stump and top

Top diameter 4.0 inches inside bark
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Total height in feet									
	20	30	40	50	60	70	80	90	100	110
	Cubic feet									
5	2.2	6.4	10.6	14.8						
6	3.9	8.2	12.4	16.6	20.8					
7	5.1	9.3	13.5	17.7	21.9	26.1				
8	5.8	10.0	14.2	18.4	22.7	26.9				
9	6.3	10.5	14.8	19.0	23.2	27.4	30.7			
10		10.9	15.1	19.3	23.6	27.1	31.5			
11		11.2	15.4	19.6	23.3	27.8	32.2	36.6		
12		11.4	15.6	19.4	23.8	28.2	32.7	37.1		
13		11.6	15.4	19.8	24.2	28.6	33.0	37.4		
14			15.7	20.1	24.5	28.9	33.3	37.7	42.2	
15			15.9	20.3	24.8	29.2	33.6	38.0	42.4	
16			16.1	20.5	25.0	29.4	33.8	38.2	42.6	
17				20.7	25.1	29.5	34.0	38.4	42.8	
18				20.9	25.3	29.7	34.1	38.5	42.9	47.3
19				21.0	25.4	29.8	34.2	38.6	43.0	47.5
20				21.1	25.5	29.9	34.3	38.7	43.1	47.6
21					25.6	30.0	34.4	38.8	43.2	47.6
22					25.7	30.1	34.5	38.9	43.3	47.7
23					25.7	30.1	34.6	39.0	43.4	47.8
24					25.8	30.2	34.6	39.0	43.4	47.9
25					25.8	30.3	34.7	39.1	43.5	47.9
26					25.9	30.3	34.7	39.1	43.5	48.0
27					25.9	30.3	34.8	39.2	43.6	48.0

Derived from: $V/B = 0.4212\ H - 189.2734/D^2$, above dotted line.

$V/B = 0.4413\ H - 413.9575/D^2$, below dotted line.

Diameter classes full-inch; e.g. 20-inch class includes 20.0 to 20.9.

Table 4.--Gross volumes in board feet Scribner Rule, ponderosa pines in the Black Hills of South Dakota and Wyoming

Board feet inside bark
Merchantable stem excluding stump and top

Top diameter 8 inches inside bark
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Total height in feet									Basis: Trees
	40	50	60	70	80	90	100	110	120	
	- - - - - - - - - - - - - - - Volume in board feet - - - - - - - - - - - - - - -									
10		34	47	61	75					30
11	31	47	64	80	96	113				52
12	43	62	81	101	120	139				64
13	56	78	101	123	146	168	198			86
14	70	95	121	147	175	210	244	278		60
15		114	144	175	214	254	293	332		67
16		134	167	212	256	301	345	389		41
17		155	201	251	301	351	401	450		44
18		180	236	292	348	403	459	515		31
19		211	273	335	397	459	521	583		28
20		244	312	381	449	518	587	655		23
21		278	353	429	504	580	655	731		14
22		314	396	479	562	644	727	809	892	12
23		351	441	532	622	712	802	892	982	11
24		391	488	586	684	782	880	978	1,076	12
25		431	537	644	750	856	962	1,068	1,174	9
26			588	703	818	932	1,047	1,161	1,276	10
27			641	765	888	1,011	1,135	1,258	1,382	12
28			696	829	961	1,094	1,226	1,359	1,491	5
29				895	1,037	1,179	1,321	1,463	1,605	5
30					1,115	1,267	1,419	1,571	1,722	1
Basis: No. trees	10	60	142	169	130	71	32	2	1	617

Block indicates extent of basic data.
Derived from $V = 0.012331\ D^2H - 34.167170$, for D^2H to 16,000
$V = 0.016318\ D^2H - 99.212720$, for D^2H larger than 16,000
Standard errors of estimate: ± 19.64 percent; 15.61 percent
Diameter classes full-inch; e.g. 20-inch class includes 20.0 to 20.9

Table 5.--Gross volumes in board feet Scribner Rule per square foot of basal area, ponderosa pines in the Black Hills of South Dakota and Wyoming

Board feet inside bark
Merchantable stem excluding stump and top

Top diameter 8 inches inside bark
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Total height in feet								
	40	50	60	70	80	90	100	110	120
	Board feet								
10		56	79	101	124				
11	43	66	88	111	134	156			
12	50	73	96	118	141	163			
13	56	79	101	124	146	169	199		
14	61	83	106	128	153	183	213	243	
15		87	110	134	164	194	223	253	
16		90	113	143	173	202	232	262	
17		93	120	150	180	210	240	270	
18		96	126	156	186	216	246	276	
19		102	132	162	192	221	251	281	
20		106	136	166	196	226	256	286	
21		110	140	170	200	230	260	290	
22		114	144	174	203	233	263	293	323
23		117	147	176	206	236	266	296	326
24		119	149	179	209	239	269	299	329
25		122	152	181	211	241	271	301	331
26			154	184	213	243	273	303	333
27			155	185	215	245	275	305	335
28			157	187	217	247	277	307	337
29				189	218	248	278	308	338
30					220	250	280	310	339

Derived from: $V/B = 2.2609\ H - 6264.6076/D^2$, above dotted line

$V/B = 2.9919\ H - 18190.8177/D^2$, below dotted line

Diameter classes full-inch; e.g. 20-inch class includes 20.0 to 20.9

Table 6.--Gross volumes in board feet Scribner Rule, ponderosa pines in the Black Hills of South Dakota and Wyoming

Board feet inside bark
Merchantable stem excluding stump and top

Top diameter 8 inches inside bark
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Number of 16-foot logs to 8-inch top											Basis: Trees
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	
	- - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	Volume in board feet	- - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	
10	31	45	60	75								30
11	37	54	72	89	107							52
12	43	64	84	105	126	146	167					64
13	50	74	98	122	146	170	194	218				86
14	57	85	113	141	168	196	224	252				60
15		97	129	160	192	224	256	287				67
16		110	146	182	218	254	290	327				41
17		123	164	204	245	285	327	375	423			44
18		137	183	228	273	318	372	425	479			31
19		152	203	253	303	360	419	479	538	598		28
20		168	224	279	338	404	469	535	601	666	732	23
21		185	246	307	377	450	522	594	666	739	811	14
22				340	419	498	577	656	735	814	893	12
23				375	462	548	634	721	807	893	980	11
24				413	507	601	694	788	882	976	1,070	12
25				452	554	655	757	859	960	1,062	1,164	9
26				493	602	712	822	932	1,042	1,151	1,261	10
27				535	653	771	890	1,008	1,126	1,244	1,362	12
28					706	833	960	1,087	1,214	1,341	1,468	5
29						896	1,032	1,168	1,304	1,440	1,576	5
30							1,107	1,253	1,398	1,543	1,689	1
Basis:												
No. trees	24	61	102	98	106	80	74	38	28	6	0	617

Block indicates extent of basic data.

Derived from: $V = 0.264267\ D^2H + 1.737800$, for D^2H to 1,200
$V = 0.312649\ D^2H - 56.188070$, for D^2H larger than 1,200

Standard errors of estimate: ± 13.22 percent; ± 11.58 percent

Diameter classes full-inch; e.g. 20-inch class includes 20.0 to 20.9

Table 7.--Gross volumes in board feet Scribner Rule per square foot of basal area, ponderosa pines in the Black Hills of South Dakota and Wyoming

Board feet inside bark
Merchantable stem excluding stump and top

Top diameter 8 inches inside bark
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Number of 16-foot logs to 8-inch top										
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
	Board feet										
10	51	76	100	124							
11	51	75	99	124	148						
12	50	75	99	123	147	172	196				
13	50	74	99	123	147	171	196	220			
14	50	74	98	123	147	171	195	220			
15		74	98	122	147	171	195	219			
16		74	98	122	147	171	195	220			
17		74	98	122	146	171	196	224	253		
18		74	98	122	146	171	199	228	257		
19		74	98	122	146	174	202	231	260	288	
20		73	98	122	147	176	205	233	262	291	319
21		73	98	122	150	178	207	236	264	293	322
22				123	152	180	209	238	266	295	324
23				125	153	182	211	239	268	297	325
24				126	155	183	212	241	269	298	327
25				127	156	185	213	242	271	299	328
26				129	157	186	215	243	272	301	329
27				130	158	187	216	244	273	302	330
28					159	188	217	245	274	303	331
29						189	217	246	275	303	332
30							218	247	276	304	333

Derived from $V/B = 48.4538\ H + 318.6285/D^2$, above dotted line.

$V/B = 57.3247\ H - 10302.1764/D^2$, below dotted line.

Diameter classes full-inch; e.g. 20-inch class includes 20.0 to 20.9

Table 8.--Gross volumes in board feet International 1/4-inch Rule, ponderosa pines in the

Black Hills of South Dakota and Wyoming

Board feet inside bark
Merchantable stem excluding stump and top

Top diameter 8 inches inside bark
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Total height in feet									Basis: Trees
	40	50	60	70	80	90	100	110	120	
	Volume in board feet									
10		38	55	71	88					30
11	35	55	75	95	114	134				52
12	49	73	96	120	143	170				64
13	65	92	120	147	179	210	241			86
14	82	113	145	181	217	253	288	324		60
15		136	176	217	258	299	339	380		67
16		163	209	255	301	348	394	440		41
17		191	243	295	348	400	452	504		44
18		222	280	338	396	455	513	571		31
19		254	319	384	448	513	577	642		28
20		288	360	431	502	574	645	717		23
21		324	402	481	560	638	717	795		14
22		361	447	533	619	705	791	877	963	12
23		400	494	588	682	776	870	963	1,057	11
24		441	543	645	747	849	951	1,053	1,155	12
25		484	594	705	815	926	1,036	1,147	1,257	9
26			647	766	886	1,005	1,124	1,244	1,363	10
27			702	831	959	1,088	1,216	1,345	1,473	12
28			759	897	1,035	1,173	1,311	1,449	1,587	5
29				966	1,114	1,262	1,410	1,558	1,706	5
30					1,196	1,354	1,512	1,670	1,828	1
Basis: No. trees	10	60	142	169	130	71	32	2	1	617

Block indicates extent of basic data.
Derived from $V = 0.015011\ D^2H - 44.360460$, for D^2H to 13,000
$V = 0.016991\ D^2H - 68.750200$, for D^2H larger than 13,000
Standard errors of estimate: $\pm$ 19.95 percent; $\pm$ 14.17 percent
Diameter classes full-inch; e.g. 20-inch class includes 20.0 to 20.9

Table 9.--Gross volumes in board feet International 1/4-inch Rule per square foot of basal area, ponderosa pines in the Black Hills of South Dakota and Wyoming

Board feet inside bark
Merchantable stem excluding stump and top

Top diameter 8 inches inside bark
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Total height in feet								
	40	50	60	70	80	90	100	110	120
					Board feet				
10		64	91	119	146				
11	49	76	104	131	159	186			
12	58	86	113	141	168	200			
13	65	93	121	148	180	211	242		
14	71	99	126	158	189	220	252	283	
15		104	134	166	197	228	259	290	
16		109	141	172	203	234	265	296	
17		115	146	177	208	239	270	302	
18		119	150	181	212	244	275	306	
19		123	154	185	216	247	278	310	
20		126	157	188	219	250	282	313	
21		128	160	191	222	253	284	315	
22		131	162	193	224	255	287	318	349
23		133	164	195	226	258	289	320	351
24		135	166	197	228	259	291	322	353
25		136	158	199	230	261	292	323	354
26			169	200	231	262	294	325	356
27			170	201	233	264	295	326	357
28			171	203	234	265	296	327	358
29				204	235	266	297	328	359
30					236	267	298	329	360

Derived from $V/B = 2.7523\ H - 8133.5644/D^2$, above dotted line.

$V/B = 3.1153\ H - 12605.4639/D^2$, below dotted line.

Diameter classes full-inch; e.g. 20-inch class includes 20.0 to 20.9

Table 10.--Gross volumes in board feet International 1/4-inch Rule, ponderosa pines in the

Black Hills of South Dakota and Wyoming

Board feet inside bark
Merchantable stem excluding stump and top

Top diameter 8 inches inside bark
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Number of 16-foot logs to 8-inch top											Basis: Trees
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	
	- - - - - - - - - - -					Volume in board feet	- - - - - - - - - - -					
10	37	54	71	89								30
11	44	64	85	106	126							52
12	51	76	100	124	149	173	198					64
13	59	88	116	145	173	202	230	259				86
14	68	101	134	167	200	232	265	298				60
15		115	153	190	228	265	303	340				67
16		130	173	215	258	300	343	384				41
17		146	194	242	290	337	384	433	482			44
18		163	216	270	323	376	430	485	539			31
19		181	240	300	358	418	479	539	600	661		28
20		199	265	331	396	463	530	597	664	731	798	23
21		219	291	362	436	510	583	657	731	804	878	14
22				397	478	559	639	720	801	881	962	12
23				434	522	610	698	786	874	962	1,050	11
24				472	568	664	759	855	950	1,046	1,142	12
25				512	616	719	823	927	1,030	1,134	1,237	9
26				554	665	777	889	1,001	1,113	1,225	1,337	10
27				597	717	838	958	1,079	1,199	1,320	1,440	12
28					771	900	1,029	1,159	1,288	1,418	1,547	5
29						965	1,103	1,242	1,381	1,519	1,658	5
30							1,180	1,328	1,476	1,624	1,773	1
Basis:												
No. trees	24	61	102	98	106	80	74	38	28	6	0	617

Block indicates extent of basic data.

Derived from: $V = 0.312621\ D^2H + 2.338510$, for D^2H to 1,100

$V = 0.318669\ D^2H - 5.939610$, for D^2H larger than 1,100

Standard errors of estimate: ± 13.18 percent; ± 10.28 percent

Diameter classes full-inch; e.g. 20-inch class includes 20.0 to 20.9

Table 11.--Gross volumes in board feet International 1/4-inch Rule per square foot of basal area, ponderosa pines in the Black Hills of South Dakota and Wyoming

Board feet inside bark
Merchantable stem excluding stump and top

Top diameter 8 inches inside bark
Stump height 1.0 foot

Diameter breast height outside bark (Inches)	Number of 16-foot logs to 8-inch top										
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
	Board feet										
10	61	90	119								
11	61	89	118	147	175						
12	60	89	117	146	175	203	232				
13	60	88	117	146	174	203	232	260			
14		88	117	145	174	203	231	260			
15		88	116	145	174	202	231	260			
16		88	116	145	174	202	231	259			
17		87	116	145	173	202	230	259	289		
18		87	116	145	173	201	231	260	289		
19		87	116	144	172	202	231	260	289	318	
20		87	116	144	173	202	231	260	290	319	348
21		87	116	144	173	202	231	261	290	319	348
22				144	173	202	232	261	290	319	348
23				144	173	203	232	261	290	319	349
24				144	173	203	232	261	290	320	349
25				144	174	203	232	261	290	320	349
26					174	203	232	261	291	320	349
27					174	203	232	261	291	320	349
28					174	203	232	262	291	320	349
29						203	232	262	291	320	349
30							233	262	291	320	349
31							233	262	291	320	349

Derived from: $V/B = 57.3196\ H + 428.7697/D^2$, above dotted line.

$V/B = 58.4285\ H - 1089.0374/D^2$, below dotted line.

Diameter classes full-inch; e.g. 20-inch class includes 20.0 to 20.9

Table 12.--Gross tree volumes per square foot of basal area by tree height classes only,

Black Hills ponderosa pine

Tree height (feet)	Merchantable cubic feet	Board feet Scribner	Board feet International	Tree height (logs)	Board feet Scribner	Board feet International
20	2.4			1.0	51	61
30	7.9			1.5	75	89
40	13.4	49	56	2.0	99	117
50	18.9	73	86	2.5	123	145
60	23.9	103	122	3.0	147	174
70	28.8	136	160	3.5	173	202
80	33.7	175	203	4.0	202	231
90	38.6	222	247	4.5	238	261
100	43.2	262	286	5.0	269	290
110	47.7	298	322	5.5	298	319
120		333	356	6.0	328	349

Table 13.--Percentage of total board foot volume in each log of a tree,

Black Hills ponderosa pine

D.b.h. (inches) and tree height (logs)	Position of log in the tree										
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
	Percent of total tree volume										
Trees 12 inches d.b.h.:											
1.0	100										
1.5	75	25									
2.0	62	--	38								
2.5	49	--	37	14							
3.0	42	--	35	--	23						
3.5	37	--	33	--	21	9					
Trees 18 inches d.b.h.:											
2.0	70	--	30								
2.5	62	--	30	8							
3.0	53	--	34	--	13						
3.5	45	--	32	--	18	5					
4.0	41	--	30	--	20	--	9				
4.5	37	--	27	--	22	--	10	4			
5.0	34	--	23	--	22	--	15	--	6		
Trees 24 inches d.b.h.:											
3.0	60	--	30	--	10						
3.5	50	--	31	--	16	3					
4.0	42	--	31	--	21	--	6				
4.5	38	--	30	--	20	--	10	2			
5.0	34	--	27	--	21	--	14	--	4		

Myers, Clifford A.
1964. Volume tables and point-sampling factors for ponderosa
pine in the Black Hills. U. S. Forest Serv. Res.
Paper RM-8, 16 pp. Rocky Mountain Forest and Range
Experiment Station, Fort Collins, Colorado.

Volumes are in total cubic feet and cubic feet to a 4.0-inch top, board feet Scribner Rule to an 8-inch top, and board feet International 1/4-inch Rule to an 8-inch top. Tree heights are in feet and numbers of logs. Volume equations are of the form $V = a + bD^2H$. Volumes per square foot of basal area are also included.

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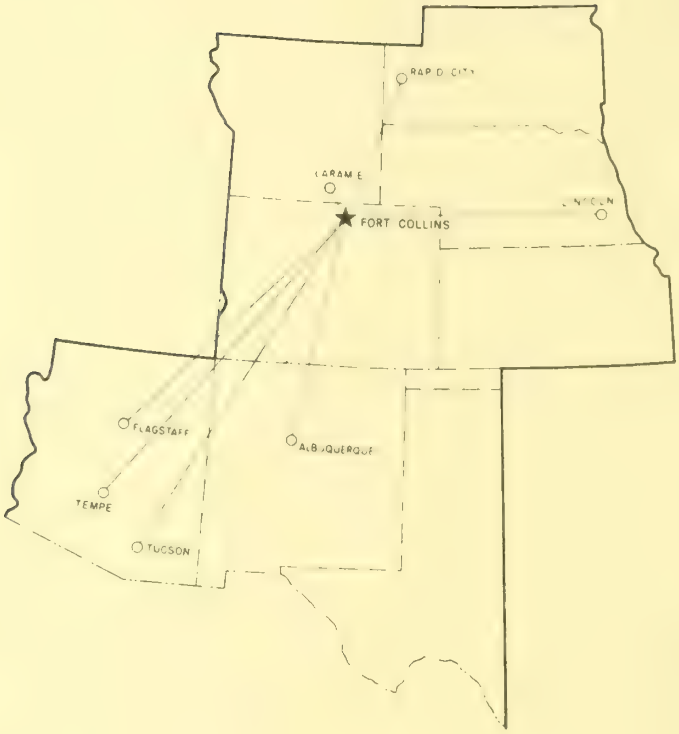
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Fort Collins, Colorado
Raymond Price, Director
FOREST SERVICE
U. S. DEPARTMENT OF AGRICULTURE

U. S. Forest Service Research Paper RM-9 December 1964

SOIL-MOISTURE FLUCTUATIONS UNDER TWO PONDEROSA PINE STANDS IN NORTHERN ARIZONA[1]

by

Waldo S. Glock,[2] Edward M. Gaines, and Sharlene R. Agerter

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[1] This project was made possible by the cooperation of the following organizations: the National Science Foundation, the Tree-Ring Research Laboratory of Macalester College, Walnut Canyon National Monument, and the Rocky Mountain Forest and Range Experiment Station with central headquarters maintained in cooperation with Colorado State University at Fort Collins. Research reported here was done in cooperation with the Station's field unit at Flagstaff, maintained in cooperation with Arizona State College.

[2] Waldo Glock is Director and Sharlene Agerter is a research associate of the Tree-Ring Research Laboratory at the Macalester College, St. Paul, Minnesota. Edward M. Gaines, research forester, formerly at Flagstaff, is now at the Pacific Southwest Forest and Range Experiment Station, Berkeley, California.

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Soil-Moisture Fluctuations under Two Ponderosa Pine Stands in Northern Arizona

by

Waldo S. Glock, Edward M. Gaines,
and Sharlene R. Agerter

INTRODUCTION

Soil moisture, or the lack of it, is of great significance in the complex of factors that influence tree growth. A knowledge of soil-moisture fluctuations can lead to a better understanding of tree growth, of seedling establishment, and of effective rainfall. Soil moisture is one important step closer to the physiological regime within the plant than is the rain that falls upon the soil surface.

The purpose of the work here described was to trace the course of soil-moisture fluctuations for a minimum interval of 3 years at two dissimilar stations within the ponderosa pine forest of north-central Arizona.

This report records the soil-moisture data and suggests possible interpretations, including influences on tree growth.

LITERATURE

A comprehensive survey of the literature that would touch upon soil moisture in all its phases is impractical in the present report. Although Kittredge (1948)[3] presents a comprehensive review of the complex relationships involved, the work of several other men should be mentioned also.

In 1931, Pearson (pp. 63-72) published soil-moisture records taken at different depths in various forest types adjacent to the San Francisco Peaks in northern Arizona. Soil-moisture determinations during the warm seasons of 1918, 1919, and 1920 were made at intervals of 2 weeks to a month. Pearson reasoned that soil-moisture profiles for the 3 years were not typical because of unusual weather conditions. The shallowness of root systems emphasized by Pearson is of great importance in both phases of the study--soil moisture and tree growth.

Colman (1944), Colman and Bodman (1944), and Schiff and Dreibelbis (1949) emphasized the speed of infiltration and percolation. Byram and Doolittle (1950), Fielding and Millett (1941), and MacDougal(1921) point out that trees respond to an increase in soil moisture directly and almost immediately. According to Byram and Doolittle, the time required by a shortleaf pine to recover from a lack of water seemed "to be determined only by the time required for the water to reach the roots."

The resumption of growth after soil-moisture replenishment, reported by several workers, illustrates the close relationship between soil moisture and tree growth when temperature does not preclude growth. In Australia, bursts of growth followed soaking rains in summer and autumn (Fielding and Millett 1941). Herman (1956) reported similar observations on Arizona junipers. In South Carolina, during the 1951 drought, the upper 66-inch layer of soil was at its wilting point most of August; trees did not grow until the September rains brought on a vigorous response (Hoover et al. 1953). In California, a pine that had ceased growing in midsummer resumed growth after it was irrigated (MacDougal 1923).

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[3] *Names and dates in parentheses refer to Selected Bibliography, p. 25.*

DESCRIPTION OF LOCALITIES

Two sites, 15 miles apart, were chosen for the installation of soil-moisture stations, one well within the zone of ponderosa pine forest (Fort Valley Station, fig. 1); the other near its lower border (Walnut Canyon Station, fig. 2). Both stations were located within 200 yards of cooperative weather stations where daily readings were taken.

Both stations were located under crowns of mature pines which would intercept some rain or snow. Both had substantial litter layers which would retain water equivalent about 1-1/2 times their dry weight (Kittredge 1948, p. 194). Hence light rains would not affect soil moisture, particularly during dry seasons. Herbaceous cover at both stations was sparse.

The forest interior station (Fort Valley) was located in a virgin stand of mature ponderosa pine on a mesalike surface underlain by basaltic lava of the San Francisco volcanic field. The site, just west of the Fort Valley Experimental Forest headquarters at 7,350 feet elevation, is near the southwest base of the San Francisco Peaks which are some 6 miles distant. No surface drainage to or away from the station was apparent; subsurface drainage (percolation) appeared to be vertical.

The lower forest-border station (Walnut Canyon) was in a mixed stand of mature ponderosa pine with a very scattered understory of pinyon, juniper, and oak brush, on a nearly flat surface underlain by arenaceous limestone (Kaibab). The study plot was near the north boundary of Walnut Canyon National Monument, at 6,750 feet elevation on the Coconino Plateau, 14 miles southeast of San Francisco Peaks. Drainage to or from the station was slight or nonexistent; percolation appeared to be vertical.

The soils recorded at the time the stations were installed differed as shown in the following descriptions:

FORT VALLEY: 4 inches of litter and humus above mineral soil.

Soil depth (Inches)	
0-18	Fine textured
18-34	Fine textured, with numerous small rocks
34-46	Cinders
46-60	Fine textured, with small rocks
60-84	Fine textured
84-96	Soil with cinders

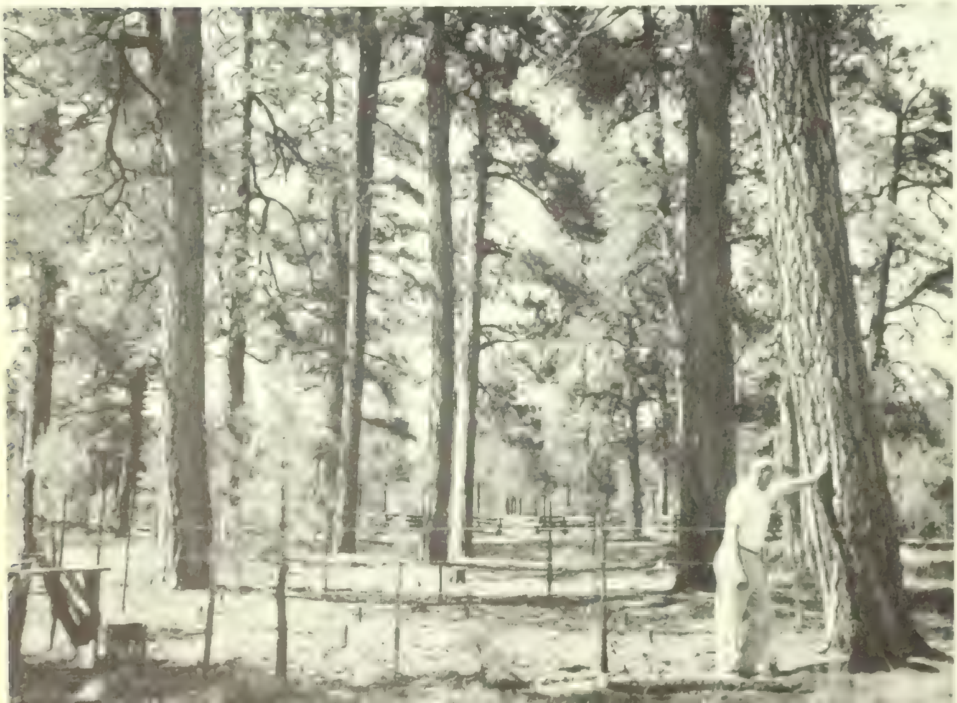


Figure 1.--The soil-moisture station at Fort Valley, located in the forest interior. The three trees plus the stile form the corners of the plot.

WALNUT CANYON: 2 inches of litter and humus above mineral soil.

Soil depth (Inches)	
0-15	Fine textured, roots numerous below 4 inches
15-22	Fine textured, with a few small rock fragments
22-34	Fine textured, with rocks
34-36	Soil with abundant roots
36-42	Firm, fine textured soil, difficult to penetrate

The two layers -- 22 to 34 inches and 36 to 42 inches -- appeared to be decomposed rock rather weakly cemented. Material was reduced to powder when brought up by auger.

On the whole, the two stations differed in (1) relation to the ponderosa pine zone, (2) elevation, (3) proximity to the San Francisco Peaks, (4) underlying bedrock, (5) depth of soil, and (6) nature and amount of precipitation.

INSTRUMENTATION

A "stack" of plaster of paris soil-moisture blocks was installed at each station, March 10-11, 1955. At the Fort Valley station, a vertical hole, 96 inches deep, was bored with a 6-inch hand post-hole auger. At Walnut Canyon, a similar hole was bored, but stopped at 42 inches after boring 6 inches in a half-cemented "hardpan" layer. In each case, the soil was separated so that each layer could be replaced in its original position.

A soil-moisture block was placed on the bottom in each hole and the soil replaced and packed, to approximately original density, around and over the block until the level for the next higher block was reached. This procedure was repeated until all blocks were placed and the hole filled.

The wires leading from the blocks were kept apart and spiraled around the hole as it was filled. At the top of the hole, the wires were led to the side and dipped about 2 inches before they emerged from the soil. These precautions minimized the chance that water could collect on and run down the lead wires. The ends of the wires were brought into a small wooden box for protection.

Readings were taken on Bouyoucos available-moisture meters, one at each station (table 3, p. 27). The meters determined percentage of available moisture, and thus re-

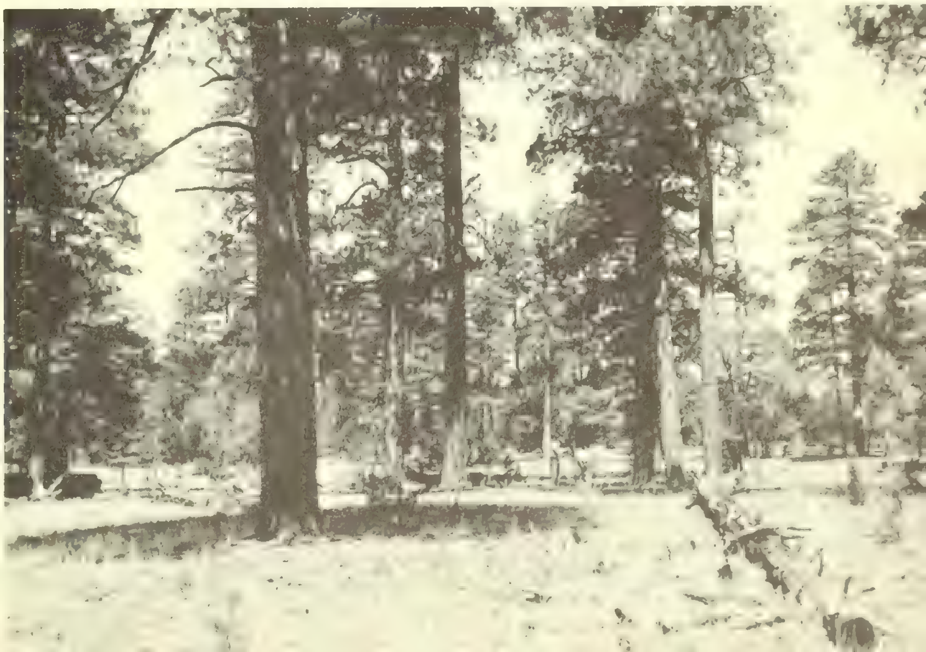


Figure 2.--
The soil-moisture station at Walnut Canyon, located near the lower forest border. These mature ponderosa pines are being used for core sampling.

corded relative rather than absolute amounts. A reading of zero on the meter corresponded approximately to the wilting point of the soil. During long periods when zero percent was recorded, soil moisture may have decreased considerably below the wilting point, and large amounts of moisture might have been required to restore the soil moisture to the wilting point before positive readings could be recorded. Long periods of high readings -- 75 to 90 percent -- may have represented field capacity of some soil layers.

The completed plot at Fort Valley (fig. 3) was laid out as shown in figure 4. A barbed wire fence enclosed the 16-foot-square area so that a walkway was left between fence and plot; the box holding the wire terminals could be reached without passing over the area immediately above the plaster blocks.

At Walnut Canyon the same ground plan was used except that the shape had to be adjusted to the position of the trees. At both stations, the stack of plaster of paris blocks was placed within the zone of lateral roots, and presumably the soil was completely occupied by roots. Depths of the various plaster blocks at the two stations were as follows:

Block number	Fort Valley (Inches)	Walnut Canyon (Inches)
1	4	4
2	8	8
3	12	12
4	18	18
5	24	24
6	36	36
7	48	42
8	60	
9	70	
10	84	
11	96	

TIME OF READINGS

Plans specified weekly readings throughout the entire year except when snow covered the lead-in boxes. In case of probable rain, a reading was to be taken within a few hours prior to the rain. Readings were to be taken also within 24 hours after a rain of 0.15 inch or more and daily thereafter until readings at all depths returned to or below values of the last reading before the rain. Although it was not always possible to follow the plans as laid out, readings were taken rather frequently for 4 years. It was noted that considerably more than 0.15 inch of rain was required to affect readings, even at the 4-inch depth.

At Fort Valley, readings were taken on five consecutive days during and after heavy rains in June 1955. Daily readings were taken in several series during July-August 1955 and July 1956. In many cases, however, readings were taken at intervals longer than a week and a few at less than a week.

At the Walnut Canyon station, there were many cases of consecutive daily readings in connection with rainfall. From June 15 to August 31, 1955, readings were taken daily, and over rather long periods they averaged oftener than weekly. The periods during which readings were taken are summarized in the following tabulation:

		Number of readings
FORT VALLEY:		
1955	May 27 - Oct. 24	67
1956	Mar. 30 - Dec. 21	56
1957	Jan. 5 - Oct. 31	44
	Nov. 4 - Dec. 3	2
1958	Jan. 14	1
	Apr. 28 - July 14	6
	Aug. 4 - Nov. 12	14
WALNUT CANYON:		
1955	May 31 - Dec. 29	104
1956	Jan. 16 - Sept. 6	80
	October	3
	Dec. 13	1
1957	Jan. 7 - Dec. 24	65
1958	Jan. 17	1
	Feb. 12	1
	June 17 - July 31	5
	Aug. 8	1
	Sept. 5 - Dec. 16	11

Two points must be recognized with respect to initial and final meter readings: In 1955, time was required for the moisture

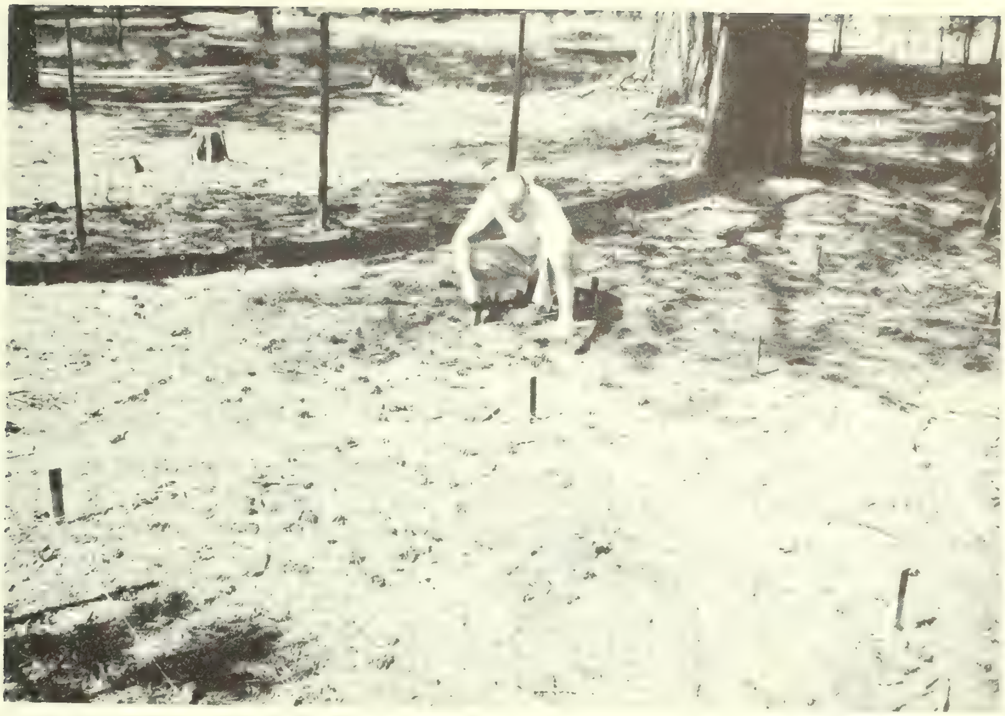
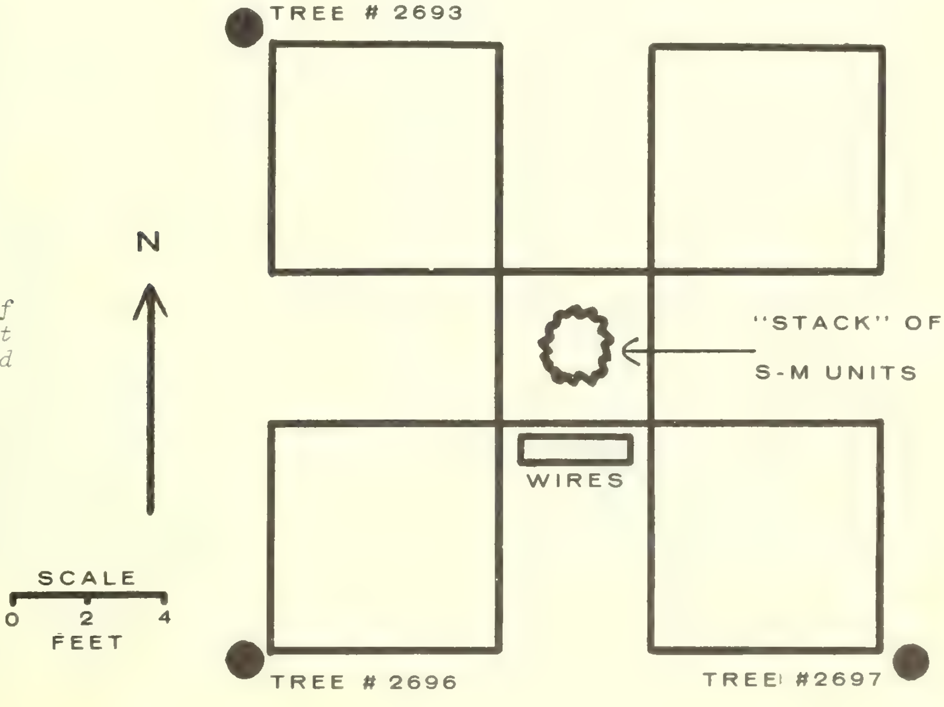


Figure 3.--Completed soil-moisture station at Fort Valley showing plot arrangement. (See figure 4.)

Figure 4.--Arrangement of soil-moisture plot at Fort Valley as pictured in figure 3.



blocks and the repacked soil column to reach equilibrium with adjacent soil and for roots to reoccupy the disturbed soil column. Meter readings were continued into October 1959 at Fort Valley and into September 1960 at Walnut Canyon. But since the plaster blocks deteriorate after 3 years of use, results became erratic. For that reason records for 1959 and 1960 were not considered in this report.

RAINFALL REGIMES

Figure 5 gives annual rainfall and monthly minimums, maximums, and averages for 4 years of precipitation at Fort Valley and Walnut Canyon. Within the span of 4 years large fluctuations were found. Such fluctuations are typical of long-term records at these stations and others of the area.

Table 1 brings together information concerning the precipitation amounts and characteristics daily, monthly, and annually at Fort Valley and Walnut Canyon for the 4 years, 1955-58. Average annual rainfall at Fort Valley for the 4 years was 22.28 inches; at Walnut Canyon, 16.88 inches. In details from month to month, the two stations recorded marked differences at certain times, especially in the summer. For example, in August 1955, rain fell at both stations on 8 days; on 10, it rained at Fort Valley only; and on 6, it rained at Walnut Canyon only. The amounts of rain varied greatly on any 1 of the 8 days when rain fell at both stations. During the 10 days with rain only at Fort Valley, 4.99 inches of rain fell; during the 6 days with rain only at Walnut Canyon, 0.67 inch fell. Summer rain on the Coconino Plateau is thunderstorm type, and may be quite localized on a particular day.

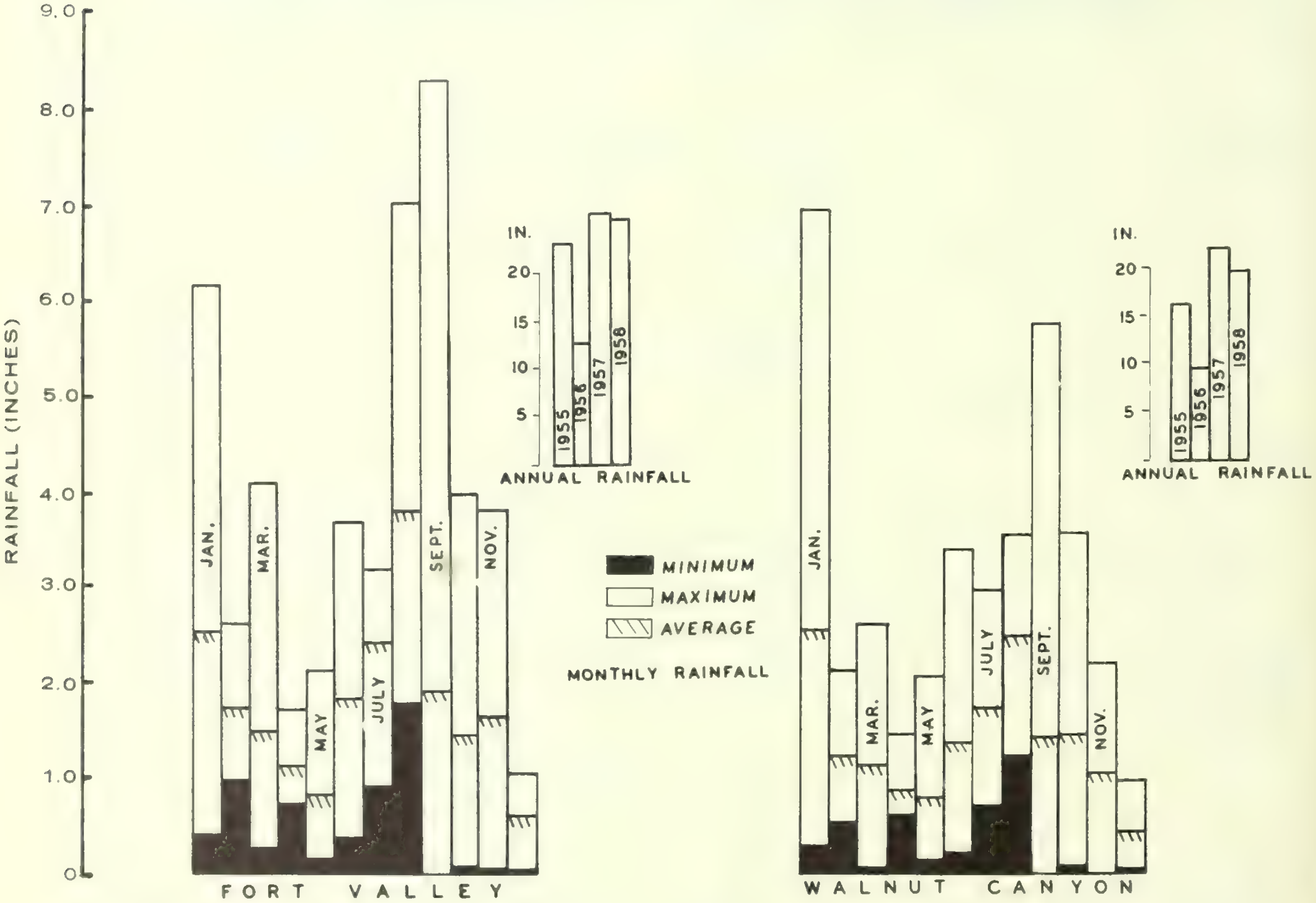


Figure 5.--The maximum, average, and minimum monthly precipitation at Fort Valley and at Walnut Canyon, plus yearly average for the four years under study.

Month	1955					1956					1957					1958				
	Amount of precipitation	Days when precipitation was--				Amount of precipitation	Days when precipitation was--				Amount of precipitation	Days when precipitation was--				Amount of precipitation	Days when precipitation was--			
		0.10 inch or more	0.50 inch or more	1.00 inch or more	Total		0.10 inch or more	0.50 inch or more	1.00 inch or more	Total		0.10 inch or more	0.50 inch or more	1.00 inch or more	Total		0.10 inch or more	0.50 inch or more	1.00 inch or more	Total
	Inches	- - - Number - - -				Inches	- - - Number - - -				Inches	- - - Number - - -				Inches	- - - Number - - -			
FORT VALLEY																				
January	3.23	9	1	0	11	2.50	6	1	0	8	6.17	15	4	1	16	0.42	1	0	0	4
February	2.34	5	2	1	7	1.00	4	0	0	6	1.06	3	1	0	5	2.63	5	3	1	7
March	.30	1	0	0	2	.47	1	0	0	3	1.31	4	1	0	9	4.10	11	3	0	14
April	.74	2	0	0	2	1.12	5	0	0	7	1.02	5	0	0	6	1.73	4	2	0	5
May	.43	3	0	0	5	.17	1	0	0	2	2.12	9	0	0	11	.85	4	0	0	5
June	3.69	2	2	2	2	1.89	1	1	1	2	1.34	3	1	0	4	.38	1	0	0	1
July	3.24	7	2	1	12	2.61	8	1	0	11	2.85	9	1	0	15	.92	2	1	0	6
August	7.05	11	5	2	14	1.80	7	0	0	10	2.42	7	0	0	13	4.09	10	3	0	19
September	T	0	0	0	0	T	0	0	0	0	T	0	0	0	0	8.35	11	7	3	13
October	.09	0	0	0	2	.82	3	0	0	5	3.96	9	5	0	11	.77	3	0	0	5
November	1.32	5	0	0	5	.05	0	0	0	1	3.81	7	3	1	9	1.38	3	2	0	4
December	1.15	3	1	0	3	.54	2	0	0	2	.85	3	0	0	5	.05	0	0	0	1
Total	23.58	48	13	6	65	12.97	38	3	1	57	26.91	74	16	2	104	25.67	55	21	4	84
WALNUT CANYON																				
January	1.78	5	1	0	7	1.47	7	0	0	11	6.93	10	6	2	12	.36	2	0	0	3
February	1.18	4	1	0	7	1.17	2	1	0	4	.51	2	0	0	3	2.13	4	2	1	9
March	.04	0	0	0	1	.32	1	0	0	4	1.66	3	2	0	4	2.68	9	1	0	12
April	.60	2	0	0	2	.92	3	0	0	7	.63	2	0	0	2	1.44	5	1	0	5
May	.65	3	0	0	3	.12	1	0	0	1	2.02	8	0	0	10	.46	1	0	0	2
June	3.38	3	1	1	3	1.34	2	1	1	2	1.10	2	0	0	2	.20	1	0	0	1
July	2.98	6	1	1	11	2.13	7	1	0	10	1.25	6	0	0	7	.70	3	0	0	7
August	3.18	8	2	0	14	1.23	5	0	0	7	2.12	6	1	0	11	3.55	7	2	1	14
September	.07	0	0	0	1	T	0	0	0	0	0	0	0	0	0	5.76	12	4	1	16
October	.05	0	0	0	1	.38	1	0	0	2	3.58	7	2	2	8	1.03	5	0	0	7
November	1.25	3	1	0	4	T	0	0	0	0	2.20	6	1	0	6	1.22	3	1	0	3
December	.98	1	1	0	1	.42	1	0	0	1	.33	2	0	0	3	.02	0	0	0	1
Total	16.14	35	8	2	55	9.50	30	3	1	49	22.33	54	12	4	68	19.55	52	11	3	80

The pattern of precipitation at the two stations differs in total amounts, in distribution details, and distribution amounts (table 3, p. 27). Records have been kept at Fort Valley for 47 years; at Walnut Canyon, 11 years. But at both stations, 1956 showed the lowest amount of precipitation recorded.

FORT VALLEY STUDIES

Infiltration and Percolation

The infiltration and percolation of soil moisture within the root zones of trees may occur in a matter of hours or days. Penetration below 12 to 24 inches may require 1 to 3 weeks. Many of the recorded fluctuations of soil moisture, however, did not lend themselves to simple and direct interpretations because of the complexity of the interrelationships among interception of precipitation by tree crowns, litter, and humus; infiltration; percolation; wetting; intensity of rainfall; cumulative rainfall; evaporation; transpiration; physiological activities of the plant cover; instrumental variations; and the long period between some measurements.

At Fort Valley in 1955 (fig. 6) moisture-meter readings fell steadily from the first reading in May until June 4, and presumably continued to fall until June 13. The rains of 3.69 inches on June 13-14 were followed by a pronounced increase in moisture readings at 4- and 24-inch depths. At intermediate depths, the increase of the already high moisture content was slight, and the percolating water passed through to the 24-inch depth. The added soil moisture penetrated to 36 inches between June 17 and 21.

Soil moisture at the 24-inch depth decreased from July 9 to August 15, whereas at the 36-inch depth it decreased until August 24. The rains of July and August up to the 15th totaled 6.40 inches in 22 days of rain. Apparently the soil moisture from these rains, aided by 2 inches on August 15 and 17, passed through the shallow depths where soil moisture was at or near field capacity, and caused a rapid rise at 24 inches during August 16-17. Nine days later the soil moisture at 36 inches suddenly increased from near zero to 75 percent of available moisture. It is to be noted, however, that this rapid rise occurred within a day after a rain of 1.28 inches on August 24.

In 1956, two contrasting situations stand out at Fort Valley (fig. 7). A rain of 1.65 inches on June 30 penetrated 8 inches in 3 days, and had very little effect at 12 inches. In spite of the heavy rain, soil moisture at 4 inches rose only from 4 to 22 percent, at 8 inches from 4 to 12 percent, and at 12 inches from 2 to 5 percent of field capacity. Percolating water did not reach 18 inches. In contrast, the frequent, small summer rains that started July 13 and accumulated 2.61 inches during the remainder of the month had no effect until after July 26. The heaviest rain of the series, 0.69 inch, came July 29; soil-moisture readings of July 30 showed a precipitous rise from zero or near zero on July 26 to 34 to 75 percent. Summer rains did not penetrate so far as 24 inches. Thus, the early single heavy rain had little effect, whereas a series of lighter rains climaxed by a moderately heavy one increased soil moisture markedly to a depth of 18 inches.

There were three situations of note at the Fort Valley station during 1957 (fig. 8). On January 5, all levels were at zero readings. Precipitation of 0.64 inch, January 4 to 6, augmented by 1.97 inches on January 8 and 9, brought a decided increase in the readings of January 11 to a depth of 18 inches. The increase had reached 24 inches at the time of the next reading, January 18; 36 inches by February 18, which was the first reading since January 25; and 48 inches on February 25. Subsequent precipitation of 2.78 inches from January 21-30 and 1.06 February 18-24 may have contributed to driving the moisture to those depths.

A second situation in 1957 occurred in connection with summer rains. The steady decline of soil moisture that began toward the end of June was arrested in an irregular fashion, to the 12-inch level only, by 4.10 inches of rain that fell on 18 different days from July 14 to August 13. The largest fall was 0.57 inch on July 18. Rains of 0.83 inch on August 25-27 brought a slight rise of soil moisture at 4 inches only.

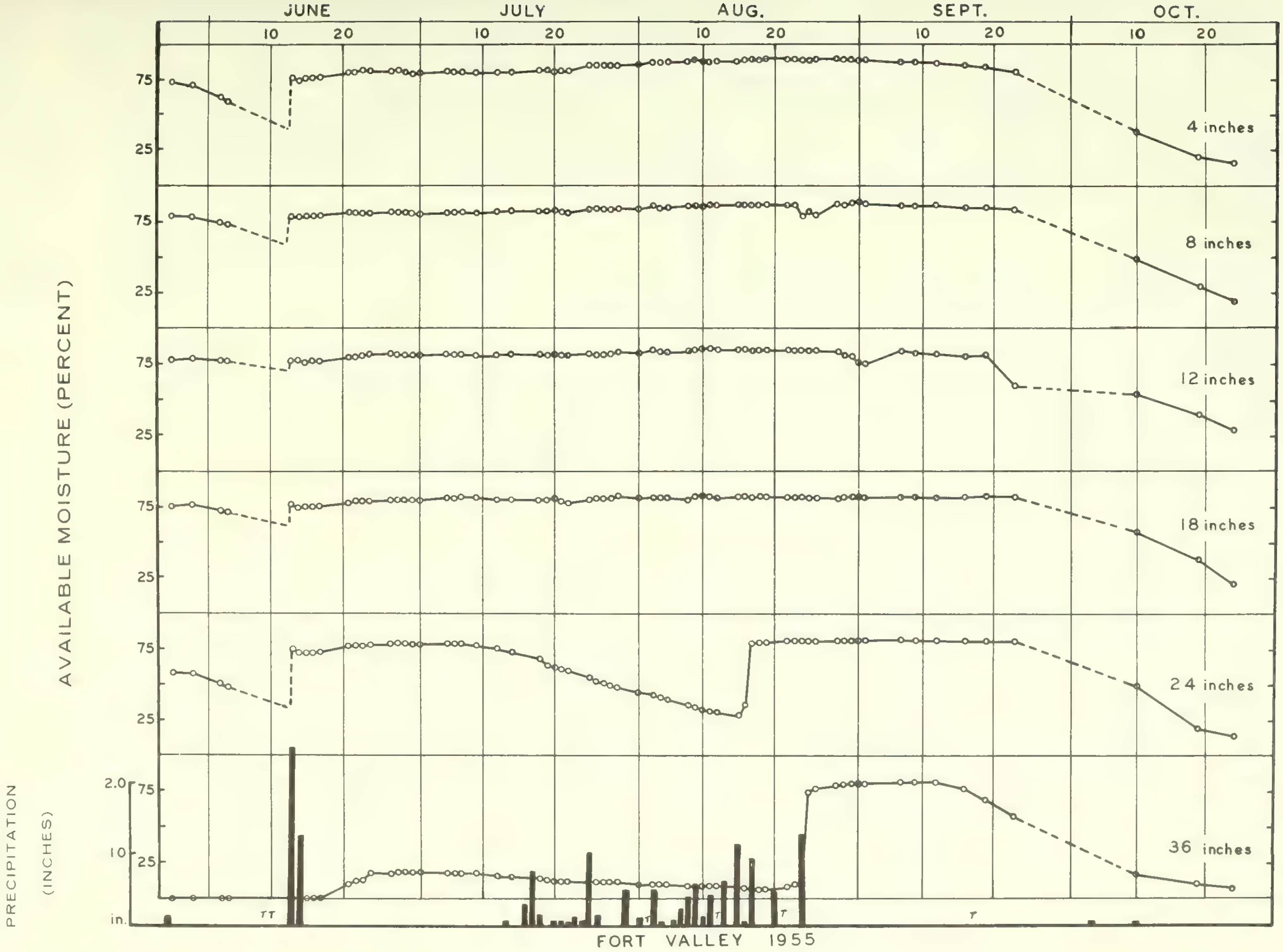


Figure 6.--Plotted soil-moisture readings and daily precipitation at Fort Valley, June-October 1955, to 36 inches. Readings at greater depths were at or near zero except at 96 inches, which registered about 18 percent at all times.

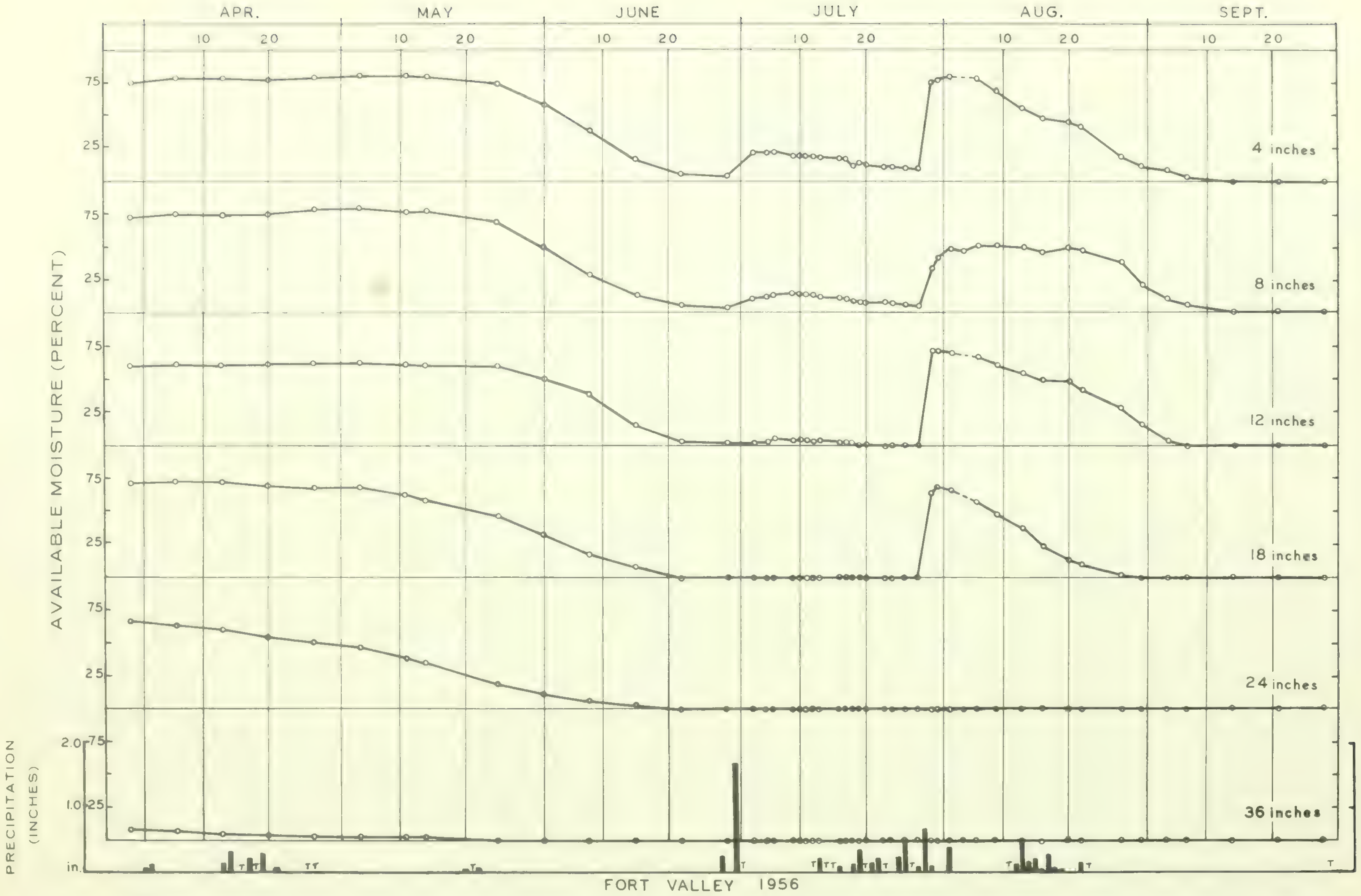


Figure [illegible].--Plotted soil-moisture readings and daily precipitation at Fort Valley, April-September 1956, to 36 inches. Readings taken October-November registered zero at all times. Readings below 24 inches were at or near zero for the entire period except at 36 inches, which showed about 10 percent.

The third situation of 1957 occurred in connection with the October rains. Available soil moisture had declined from July through September to near zero at all depths except 96 inches. The 1.83 inches of rain October 11-13 brought an abrupt rise in the readings of October 14 to the 18-inch depth. Readings at the 24-inch level remained at zero until after October 31. Additional rains, culminating in 2.06 inches on November 3-4, apparently caused a rise to 81 percent on November 4. These same rains may have caused the slight rise at the 18-inch depth. A reading taken a month later, December 3, showed that a slight rise in soil moisture had occurred at 36 inches at some time between readings. No additional moisture was detected at 48 inches.

A total of 17.50 inches of precipitation was recorded from October 1, 1957, to April 30, 1958. On April 28, soil moisture was high throughout the full 96-inch profile, except for the 36-inch level. Attempts to explain this disparity would be largely speculative. By contrast, 10.97 inches during the same period on 1956-57 raised soil moisture only through the 48-inch depth, and 7.65 inches in 1955-56 only through the 24-inch depth. The long-term average precipitation for this 7-month period is between 13 and 13-1/2 inches.

Two other situations in 1958 are worthy of comment, one in connection with single light rains of early summer and the other with continued rains of late summer (fig. 9). The rain of 0.38 inch on June 22 after 22 rainless days did not halt the decline of soil moisture as measured 4 days later. It may not even have penetrated the litter layer. The rain of 0.58 inch on July 24, after another 32 rainless days, was not apparent in the soil on August 4. Down to 36 inches, available soil moisture was very low or near zero on August 4. The accumulated rains of late July and early August caused a rise in soil moisture by August 11, slight at the 4- and 8-inch levels but pronounced at the 12- and 18-inch levels. The additional heavy rains of early September apparently forced moisture through to the 24-inch depth, and later, in irregular pattern, to 48 inches.

Soil-Moisture Patterns

Soil-moisture fluctuations at Fort Valley were not uniform from year to year. With two wet seasons a year, two general periods of high soil-moisture content might be expected. They do not necessarily occur, as there is great variation in precipitation among seasons. In 1955, soil moisture remained high at the first four levels through the early summer dry season and did not begin to decrease until well into the autumn dry season. The July decline of soil moisture at 24 and 36 inches was reversed sharply in August, a result perhaps of the percolating waters from summer rains. Possibly roots did not effectively reoccupy the disturbed soil column until late summer.

Total precipitation at Fort Valley during 1956 was the lowest in 47 years of record. Soil moisture was high only through the 24-inch depth after the winter wet season and declined into the early summer dry season. Summer rains increased soil moisture sharply down to 24 inches. By mid-September soil moisture was at zero percent, where it remained presumably until the start of the next winter wet season. The curve of soil moisture during 1956 traces a double-crested graph to match a double rainy season.

The beginning of the winter wet season in January 1957 restored soil moisture to a high level through the 48-inch depth, where it remained until well into the early summer drought. The summer rains came as frequent but generally light showers, and the general decrease of soil moisture continued into the autumn dry season, with only a slight and irregularly placed temporary delay in August down to 12 inches. Apparently interception, evaporation, and transpiration generally exceeded rainfall. October-November rains restored soil moisture to rather high levels -- down through 24 inches. Thus, the soil moisture of 1957 stands in an intermediate position between 1955, with one time of decided dearth of soil moisture, and 1956 with two marked intervals of low moisture.

The year 1958 had two times of declining soil moisture as did 1956, but in contrast with 1956 the early summer drought was longer and not so intense, and the rise in soil moisture due to the summer rains was greater and continued much longer. Heavy September rains restored soil moisture through the 48-inch level.

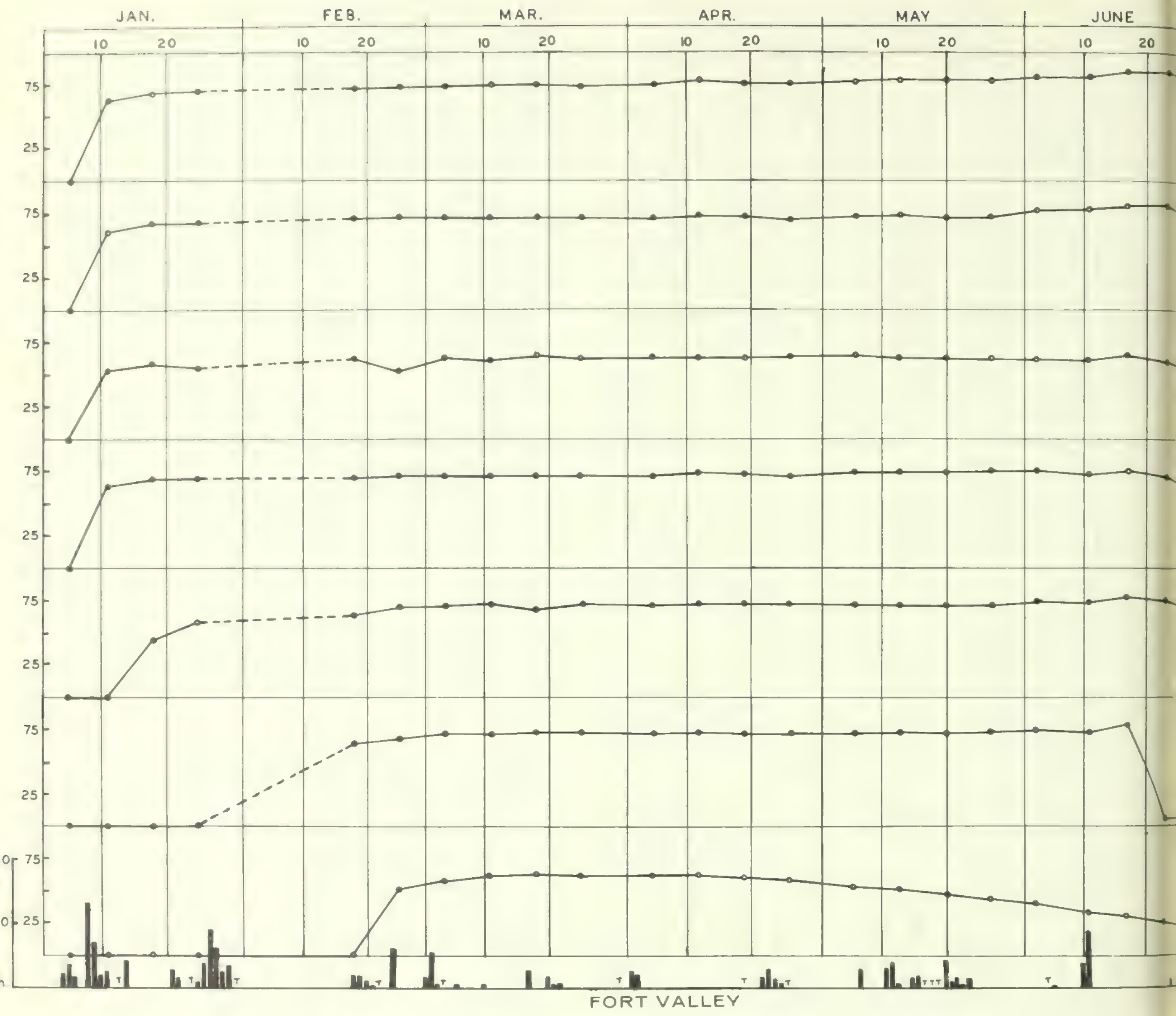
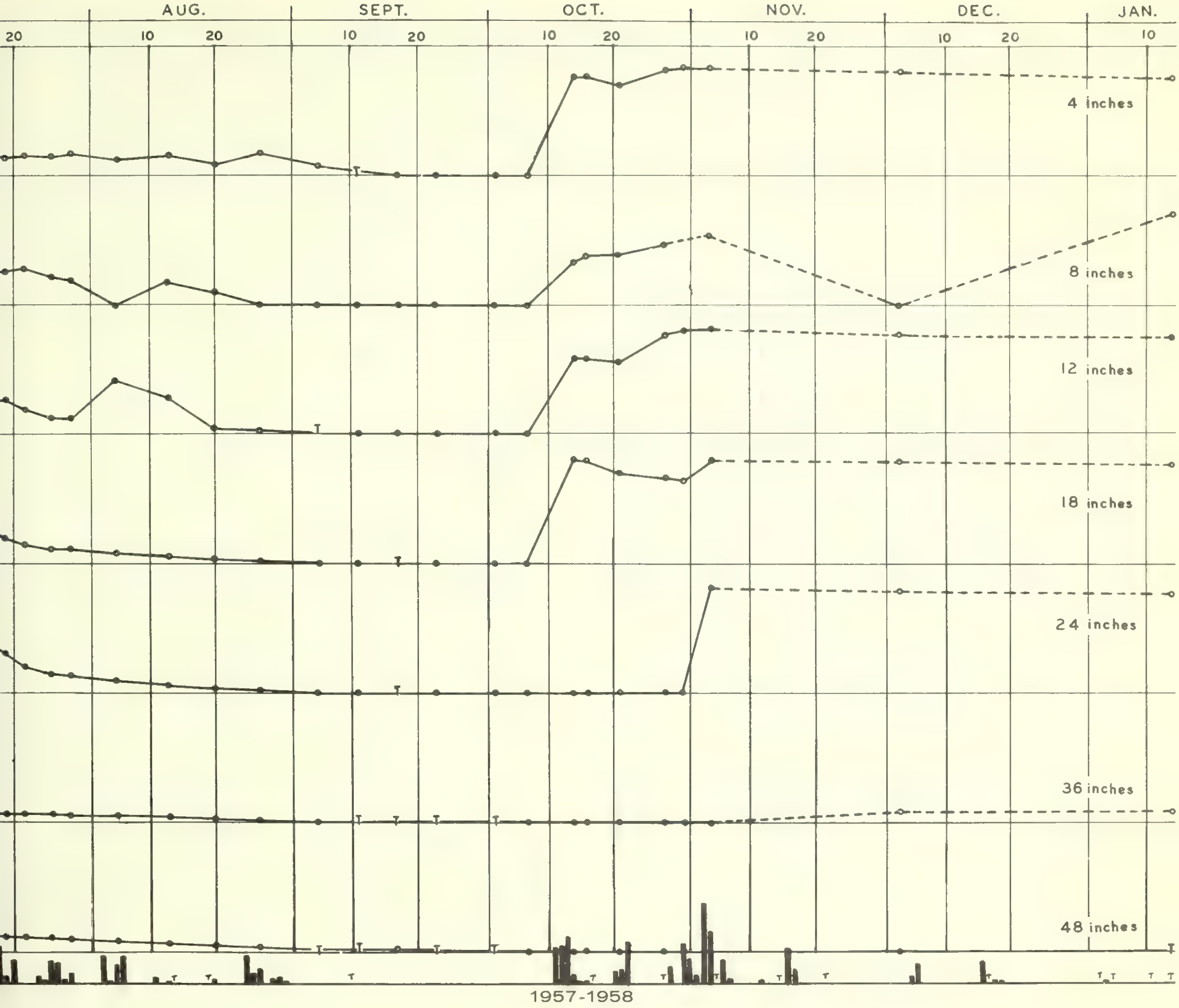


Figure 8.--Plotted soil-moisture readings and daily precipitation at Fort Valley, January 1957–January 1958, to 48 inches. Readings below 48 inches were at or near zero except at 96 inches, which fluctuated around 10 percent.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1957-1958

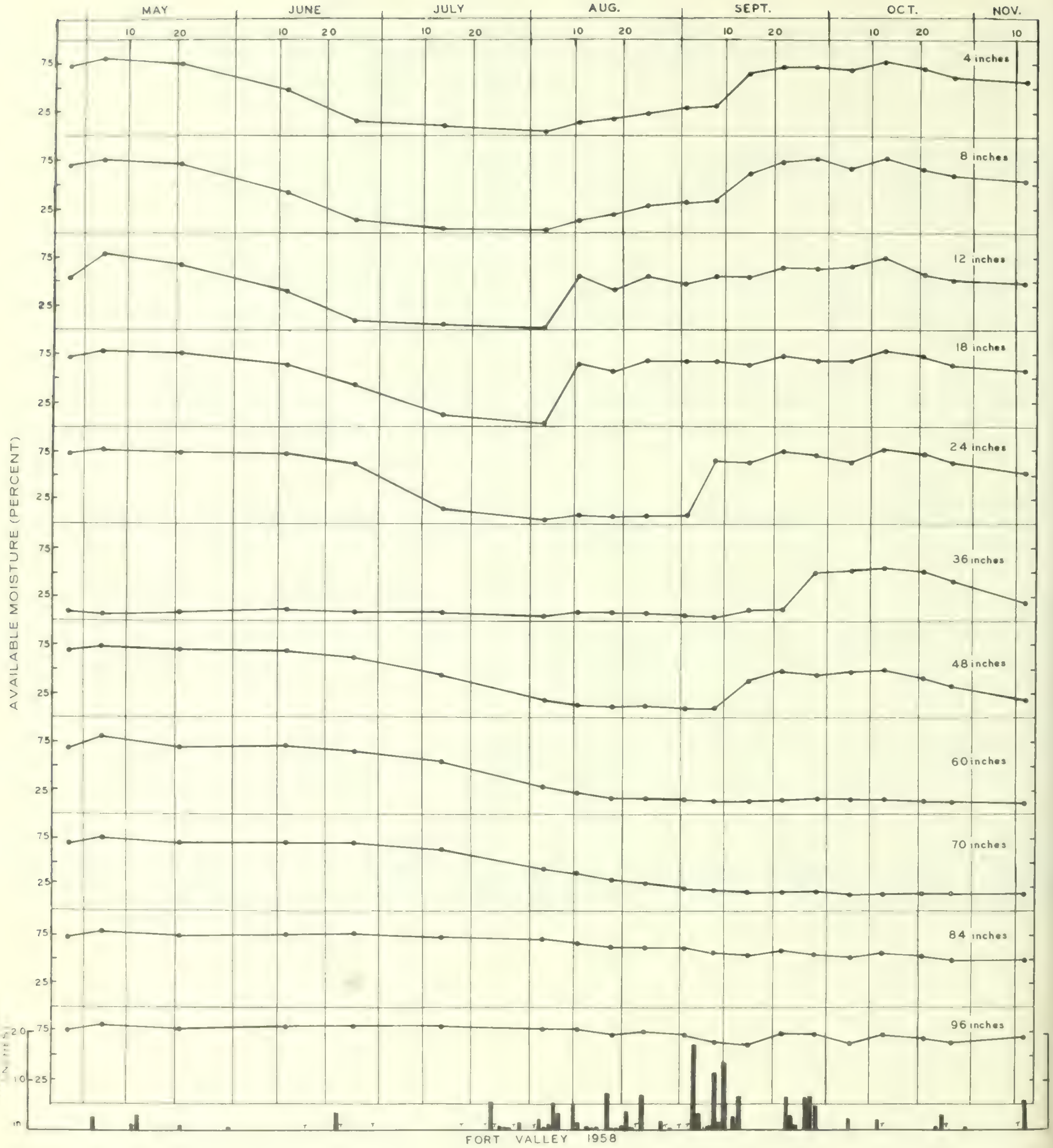


Figure 9.--Plotted soil-moisture readings and daily precipitation at Fort Valley, May-November 1958, to 96 inches.

At Fort Valley, soil-moisture records for the 4 years, 1955-58, differed from each other in detail. Winter precipitation comes at a time when vegetation in general is dormant and transpiration from conifers at a minimum. The precipitation is effective in recharging the moisture in the deeper layers of soil. Summer precipitation, coming at a time when vegetation is active and transpiration at a maximum, rarely penetrates to levels where it contributes to the deep soil-moisture reservoir.

WALNUT CANYON STUDIES

Infiltration and Percolation

At Walnut Canyon in 1955 (fig. 10), the rain of 3.05 inches on June 13 had a spectacular influence at 4, 8, and 12 inches. Arrival of the moisture at 8 inches was delayed not more than 2 days (no readings on June 14). It raised the moisture level at 12 inches from near zero to 80 percent, starting within 2 days and continuing through 11 days. In July, with a fair amount of soil moisture remaining at the upper three levels (possibly because roots had not yet reoccupied the disturbed soil column), the response to rainfall on three successive days was more gradual than in June. The summer rains appear to have had only slight effect at 18 inches. Speed of depletion of moisture of the upper three soil levels and its dependence on the immediate rains are well illustrated by the June-September graphs. In contrast with rapid responses of soil moisture to rainfall at shallow depths during the summer, precipitation of 0.62 inch on November 13 and 0.33 inch on November 14 had not affected the 4-inch depth by November 15. Precipitation of November and early December apparently did not penetrate to the 12-inch depth.

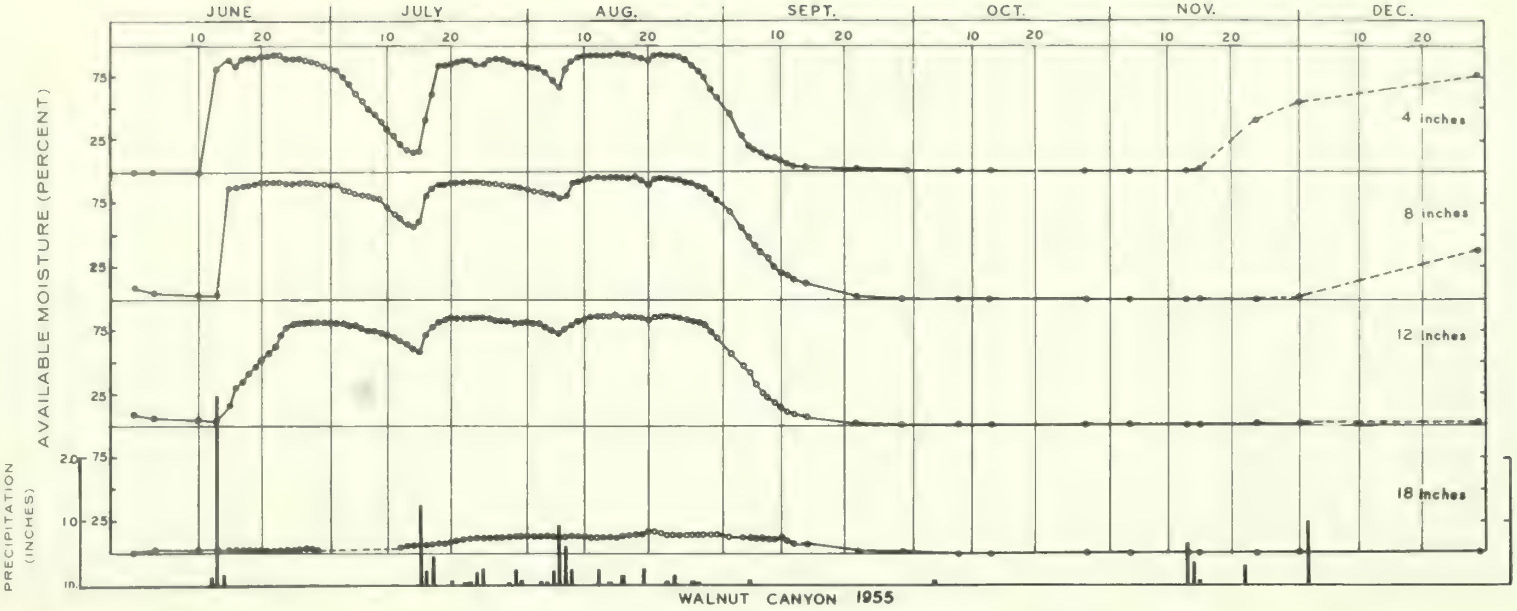
Soil moisture increased through February and March 1956 (fig. 11), because of the January-February precipitation, but only through the 12-inch depth. Readings of February 18, the first since January 28, showed an increase of soil moisture at the 4- and 8-inch depths. At the 12-inch depth, the increase appeared at the next reading on February 28.

The summer rains of 1956 consisted of a heavy rain in late June and scattered rains in July-August. Their effects did not reach to 8 inches. Rains of 1.44 inches on June 28-30 caused an increase of soil moisture at 4 inches, from zero on June 27, to 20 percent on June 30, and 75 percent on July 2. Here, a heavy rain produced a rapid response in soil-moisture replenishment at shallow depths.

Nearly 1.6 inches of rain scattered over an interval of 11 days in late July caused a steady and moderate increase of soil moisture at 4 inches only. The light, scattered rains of August may have delayed somewhat but did not prevent the decrease of soil moisture to zero percent at 4 inches even before the rains ceased.

In 1957, soil moisture increased rapidly and to a great extent in connection with precipitation of January and with rains of October-November, and increased slightly and more slowly, at 4 inches only, in connection with those of May-June (fig. 12). Precipitation of 1.72 inches on January 8 increased soil moisture at 4 inches from zero on January 7 to 75 percent on January 9. At 8 inches, soil moisture showed an increase between January 10 and 12, and reached a high point on January 16. The increase at 12 inches started 3 days later than at 8 inches. Precipitation of late January appeared to have passed through the upper levels, high in soil moisture at the time, and to have reached the 18- and 24-inch levels between February 8 and 11. Three additional days were required for the soil moisture to pass from 24 inches to 36 inches. Increase at 42 inches was more gradual; maximum was reached in late March.

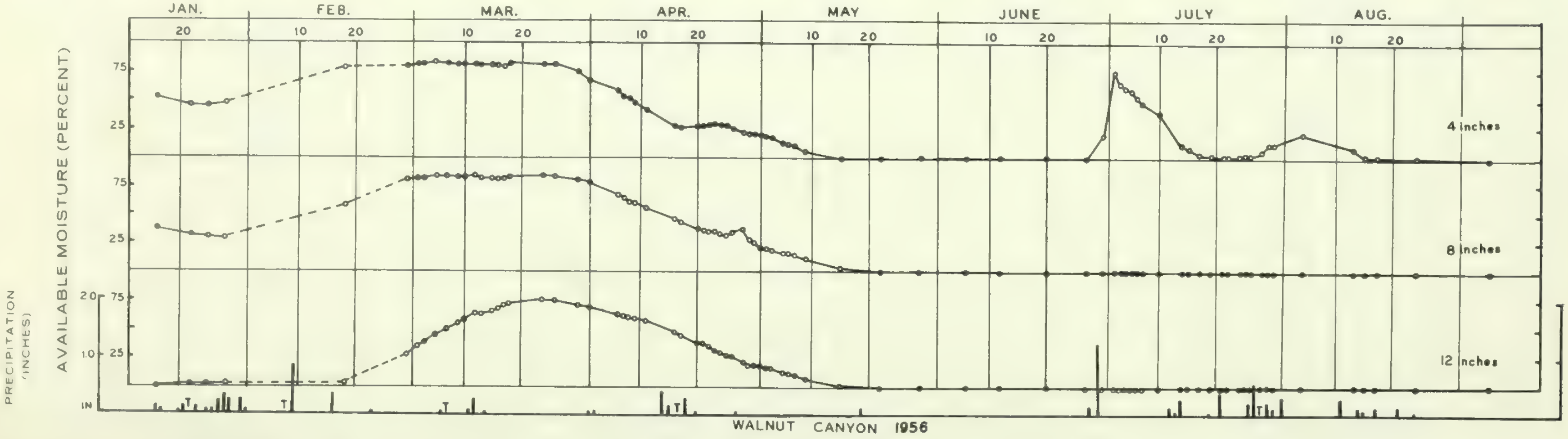
The rains of October-November 1957 penetrated effectively to the 24-inch level. Rains of 1.50 inches on October 11-12 had no effect at 4 inches until the reading dates, October 14-16, after which there was a gradual increase in soil moisture, to a maximum on November 4. Apparently the fall rains did not affect soil moisture below the 4-inch depth until the storms of the 4-day period, October 31 to November 3, which totaled 2.53 inches, increased soil moisture at the 8- and 12-inch depths from zero on November 1 to 80 percent on November 4. Available soil moisture at 18 inches remained at zero at least until November 7, 3 days after the peak at 12 inches. The peak at 18 inches was recorded on November



PLOTTED SOIL-MOISTURE READINGS AND DAILY PRECIPITATION AT WALNUT CANYON.

Figure 10.--June-December 1955, to 18 inches. Readings at greater depths near zero except at 42 inches, where they fluctuated around 17 percent until October when they started to decrease.

Figure 11.--January-September 1956, to 12 inches. Readings remained at zero until December 13. Readings at greater depths were at or near zero except for 42 inches, which fluctuated around 14 percent until the end of May when it also dropped to near zero.



15, and at 24 inches on November 20. At greater depths the rains of autumn had a very slight effect.

Gaps in the record and long intervals between readings prevent detailed interpretation of infiltration and percolation in 1958. Readings of August 8, 1958, showed zero available moisture above 42 inches (fig. 13). Eighteen rains from August 2 through September 4 totaled 4.70 inches, with one rain of 1.56 inches on August 17. On September 5, the 4-inch level showed 56 percent available moisture; the 8-inch, 28 percent; and the 12-inch, 3 percent. The 2.50 inches of rain from September 23-28 apparently passed through the already moist 4- and 8-inch levels with slight and moderate effects, and brought the 12-inch reading up sharply in the readings of September 29. No increase in soil moisture was detected at 18 inches until October 8; 4.68 inches of rain had fallen since September 4. Here, as in former years, summer rains penetrated only the shallow layers of soil.

Soil-Moisture Patterns

The soil-moisture regime at Walnut Canyon appeared more regular than that at Fort Valley, and dry periods were longer and more intense. When soil-moisture readings were begun at Walnut Canyon in early June 1955, available moisture was near or at zero percent down to 36 inches. A single heavy rain and the general summer rains brought a rapid rise in soil moisture, which then remained high until late August. Again, we may presume that roots did not reoccupy the disturbed soil column until late summer. Low soil moisture during early summer and autumn droughts separate intervals of high soil moisture of the two rainy seasons, thus giving a soil-moisture regime, at shallow depths, consistent with what one would expect from the precipitation.

In 1956, the winter precipitation increased soil moisture down to only 12 inches. The late spring-early summer dearth of soil moisture continued into January 1957 except at 4 inches, where the summer rains brought a sharp but temporary increase.

Soil-moisture fluctuations of 1957 bear little resemblance to those of 1955 or of 1956. A late-summer increase is entirely lacking, presumably because July-August rains were light and scattered. High available soil moisture of January-March began to decline in April, and with only a brief hesitation at shallow depths reached zero or near zero percent during July. No perceptible change occurred until the rains of October and early November brought a rapid increase down to 24 inches. Rains that fell in July and August did not cause a crest in soil moisture.

Thus at Walnut Canyon the 3 years of 1955-57 present three types of soil-moisture regimes: 1955 with its summer abundance of soil moisture bounded by a lack of soil moisture before and after the summer rainy season; 1956, a very dry year, with its slight response to summer rains; and 1957, a year of much early and late rain, with no distinct summer crest of soil moisture when rain was below average.

The abundance of soil moisture in late 1957 continued into the winter of 1958. When the record began again in June-July 1958, readings were near or at zero. The increase that came later was not a "typical" summer increase, but was displaced from July-August to September-October.

At Walnut Canyon as at Fort Valley, amounts of annual precipitation varied and the distribution changed from year to year. On long-time averages, two crests of soil moisture would be expected each year, one during winter and the other during summer. For any particular year the general rule does not necessarily apply, as the 4 years of record illustrate.

COMPARISON OF SOIL-MOISTURE FLUCTUATIONS

The variations in soil moisture from year to year are generalized in figure 14 for Fort Valley and in figure 15 for Walnut Canyon. Winter crests are more uniform and persistent than summer crests. Annual totals, period totals, or even monthly totals of precipitation can form no constantly safe guide to the amounts of soil moisture available at any specified time. Integration of data on size and

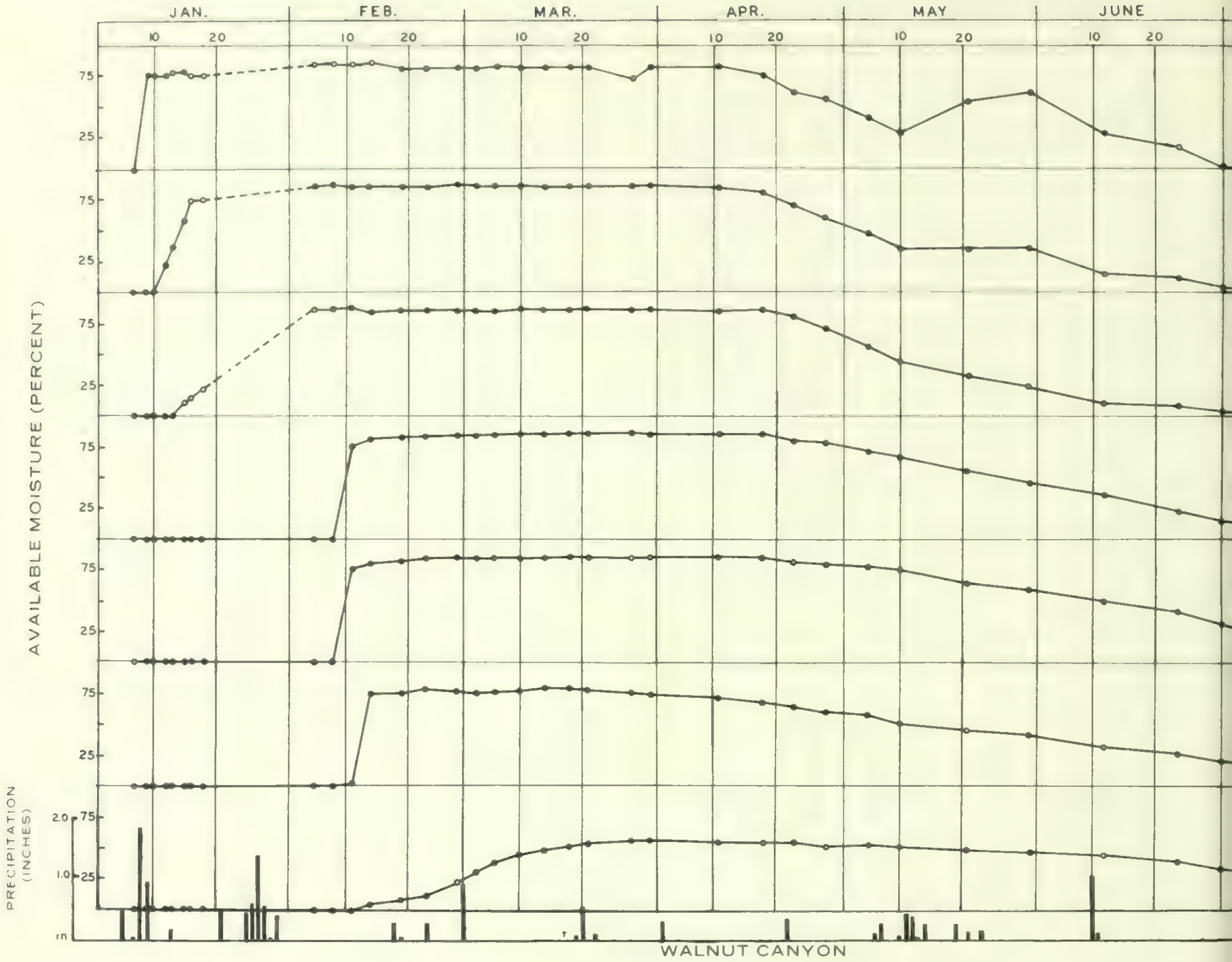
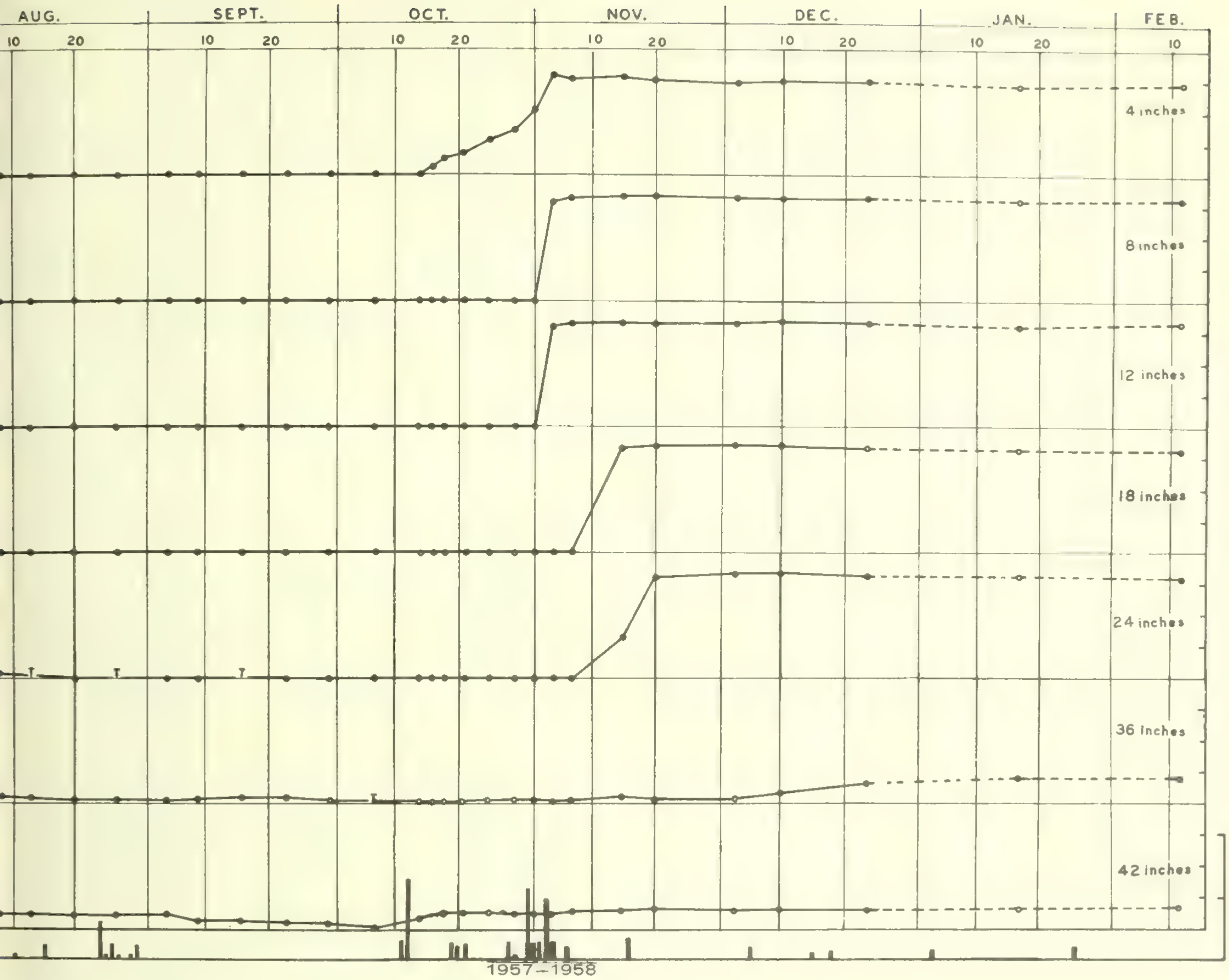


Figure 12.--Plotted soil-moisture readings and daily precipitation at Walnut Canyon, January 1957-February 1958, to 42 inches.

spacing of storms, adjusted for season and existing soil moisture, might provide a better guide.

Insofar as records are available, the gross features of the graphs on figures 14 and 15 are much the same. Soil moisture at Walnut Canyon is not so plentiful or so long continuing as at Fort Valley. Smaller amounts of precipitation fall on shallower soil. There are differences in detail. A high percentage of soil moisture at Fort Valley does not always indicate a high percentage at Walnut Canyon.

One point of special significance to hydrology stands out in a comparison of summer and winter percolation. Summer rainfall seldom penetrated through the shallow soil layers to the deep layers. Only winter precipitation penetrated to a depth sufficient to recharge the deep-soil reservoir, and this only with ample precipitation. The tendency for moisture to remain constant in the deep layers of soil probably means that few, if any, roots exist at these levels. In fact, the rate of moisture depletion at different depths might be used to interpret the effective depth of root systems.



SOIL MOISTURE AND TREE GROWTH

The role of soil moisture in relation to tree growth and the problems inherent in a study of these relationships are brought to a focus in the apt title: "Trees also need water at the right time and place" (Hayes and Buell 1955). Pearson (1918, 1924, 1931, 1950) mentioned the importance of the growing season and the position of feeder roots. Time growth begins in the spring is largely attributed to temperature. Moisture no doubt contributes to amount of growth and time of cessation.

The frostless period at the Fort Valley and Walnut Canyon stations commonly extends from early June to late September (Pearson 1931, p. 19), but at Walnut Canyon the period is several days longer. From information given by Pearson (1931, pp. 22-31) it may be inferred that mean maximum, mean minimum, and mean monthly temperatures are several degrees lower at Fort Valley than at Walnut Canyon.

The position of feeder roots bears a distinct relationship to fluctuations of soil moisture. According to Pearson (1931, p. 64), "the

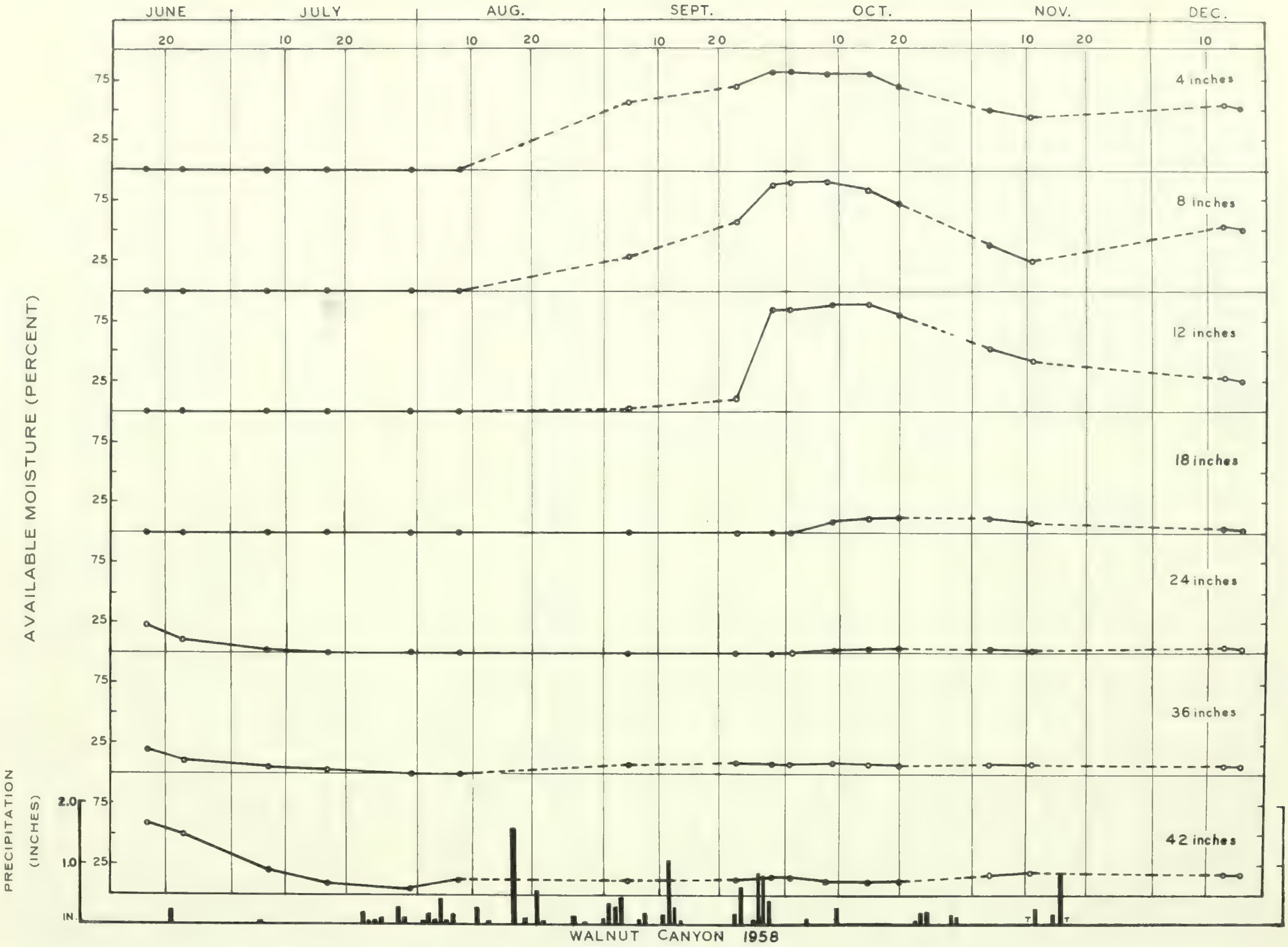


Figure 13.--Plotted soil-moisture readings and daily precipitation at Walnut Canyon, June-December 1958, to 42 inches.

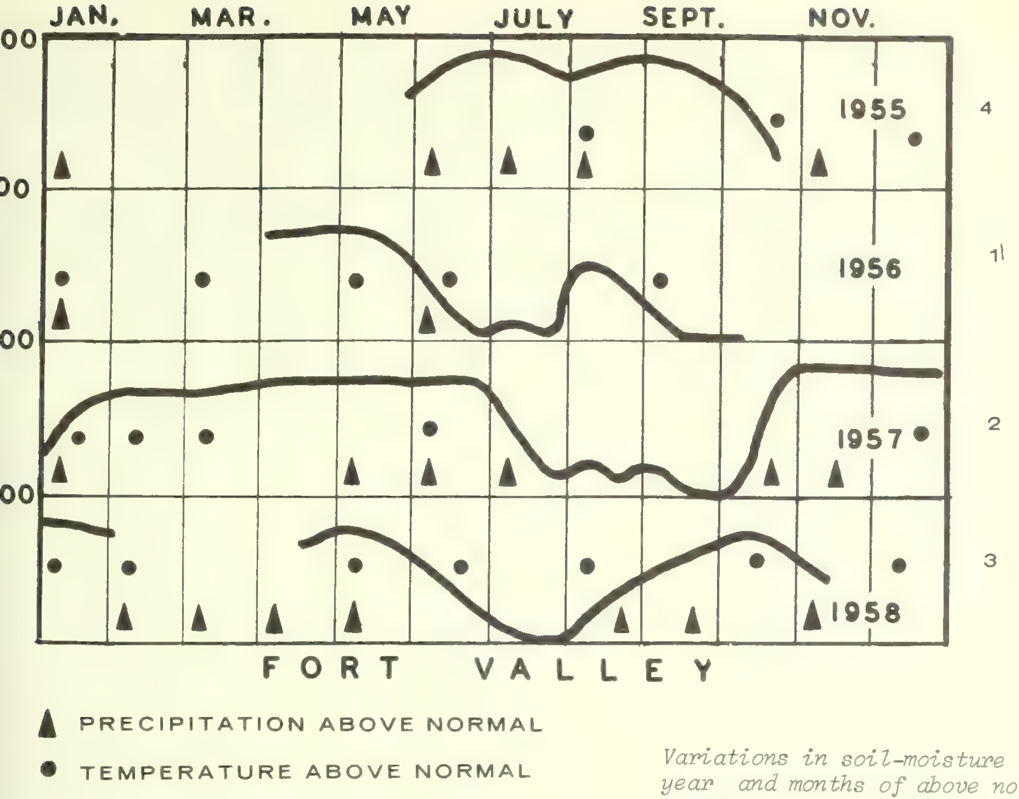


Figure 14.--
FORT VALLEY

Variations in soil-moisture regimes from year to year and months of above normal temperature and precipitation. Numbers at right margin are increasing thickness of growth layers.

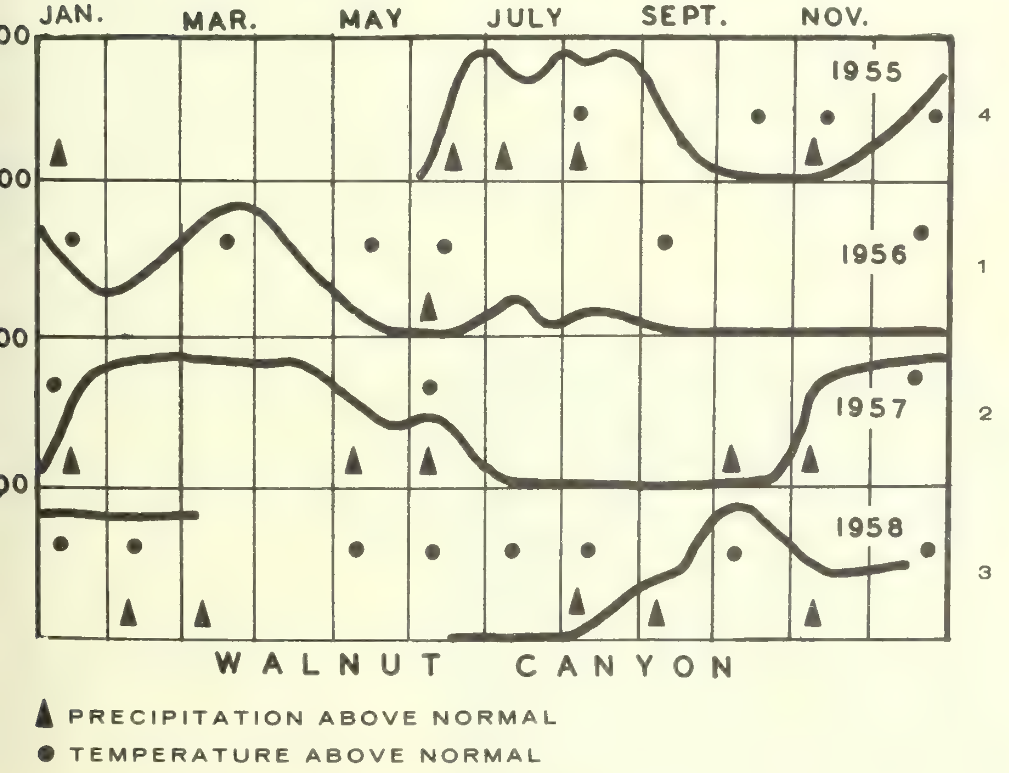


Figure 15.--
WALNUT CANYON

great mass of feeders lies within 2 feet of the surface." Under certain soil conditions roots may penetrate to a depth of 4 feet, or slightly more. Observations of windthrown trees and of root systems exposed in cinder pits over a period of many years have supported Pearson's statements. Figure 16 shows the flat lateral root system of a windthrown ponderosa pine just west of the Fort Valley station headquarters. Although the flat mass, 6 to 18 inches thick, might be thinner than the average, it illustrates the typical root system observed not only in the vicinity of the soil-moisture stations, but also extensively throughout the ponderosa pine zone of northern Arizona. The great mass of feeder roots are no doubt confined to the shallow layers where moisture is frequently available during the active growing season. The rate and amount of summer moisture depletion at different depths probably indicated the effective depth of root systems.

Elongation, or tip growth begins in May, proceeds rapidly in June, then slows and ceases early in July (Pearson 1924, p. 203; 1931, pp. 19, 99). Our observations for the past 12 years have shown that tip and needle growth at a certain time have been more advanced in general at Walnut Canyon than at Fort Valley.

Figure 17 gives percentage of radial growth by certain dates of the years 1954-61 for the two groups of ponderosa pine averaged for each station. Incomplete growth of a year was compared to completed growth of the same year of all cores taken subsequently. Hence, from 1954 to 1961 there was a decreasing number of growth layers from which to obtain the percentage of completion.

Individual trees show considerable variations from the average; cores taken at both stations showed that the range in percentage of completeness appeared to be less at Walnut Canyon than at Fort Valley, as follows:

	Percent
Fort Valley:	
July 28, 1956	62-100
August 14, 1959	46-100
July 9, 1960	21- 60
August 1, 1960	38- 87
July 3, 1961	16- 56
July 29, 1961	47-100
Walnut Canyon:	
July 25, 1956	28-100
Aug. 12, 1959	85-100
July 8, 1960	83-100
June 29, 1961	61- 96
July 24, 1961	84-100

Cores taken at both stations showed growth had been completed by October 6, 1961.

Perhaps the most important fact shown by figure 17 is the percentage of the year's growth attained: a higher percentage had been completed by a certain date at Walnut Canyon than at Fort Valley.

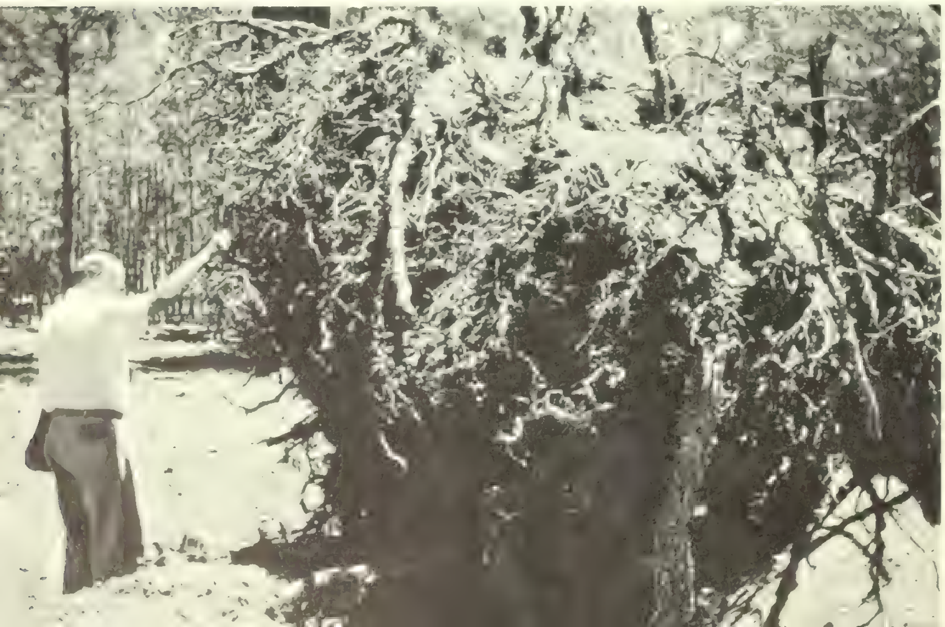


Figure 16.--
"Pancake" root system of a windthrown ponderosa pine west of Fort Valley station headquarters.

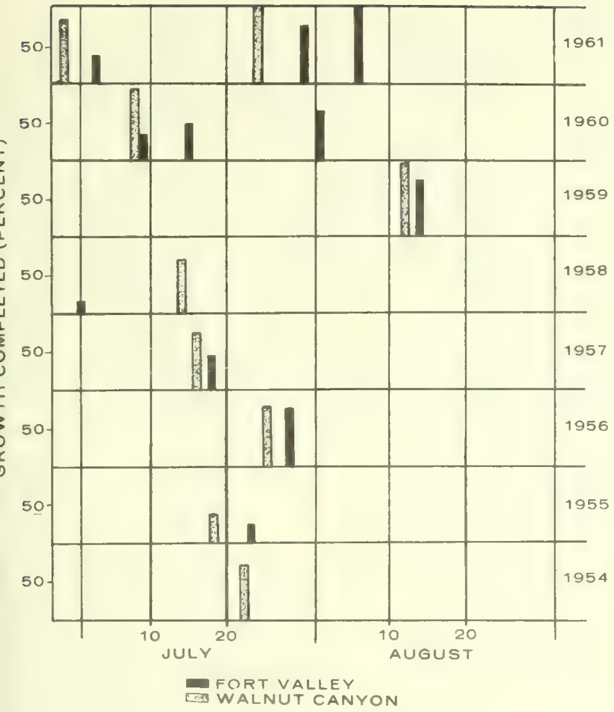


Figure 17.-- Percentage of growth completed by various dates in July and August for trees at Fort Valley and at Walnut Canyon.

Diameter growth (Pearson 1924, pp. 203-204; 1931, p. 19) begins the latter part of May and is practically complete by September 1. This does not mean that growth must continue that long, that it must be continuous, or that it must be parallel in time or amount at Walnut Canyon and Fort Valley. A test made the first part of July at Walnut Canyon showed diameter growth in a mature ponderosa pine equaling the average growth-layer thickness of the previous 10 years. There was no evidence of densewood (summerwood). In contrast a test made at the same time at Fort Valley showed only one to two rows of new cells, which indicated that growth had just begun. This was not an isolated instance.

Many ponderosa pines at Fort Valley, Walnut Canyon, and several other localities in the vicinity of Flagstaff have been observed and cored since 1949. Before 1949, cores were taken every 2 or 3 years; since 1958, cores have been taken two or three times each year. Since the soil-moisture stations were established, trees whose root zones surrounded the plaster blocks, and two others in the immediate vicinity, were added to those sampled. The number of cores used in the averages for each year varies from 25-39 for 1955 to 17-25 for 1958. Except for 1956 little relationship was found between growth-layer thickness and precipitation, either annual or period. July-August rainfall appears to have a somewhat closer relationship to growth-layer thickness than do the other rainfall periods. The relationship is neither close enough nor sufficiently prolonged to be more than suggestive.

Information for Fort Valley and Walnut Canyon is summarized as a matter of convenience for each year, beginning with the year of the thinnest growth layer (table 2).

The length of record, 4 years, is inadequate for more than tentative conclusions. When readings began the end of May 1955, the plaster blocks may not have quite attained equilibrium with the soil and its moisture, and tree roots may not have reoccupied the disturbed soil until even later in the summer. Some of the blocks may have failed as early as 1958.

Temperatures during the growing season apparently were not prime controlling factors in the thickness of the growth layers. The year 1955, which produced the thickest growth layer of the period 1955-58, had temperatures below normal January to July. August was above normal. In 1956, which produced the thinnest growth layer of the period, temperatures were above normal May-June and below normal July-August.

Soil moisture appears to be more directly related to growth than is temperature. The thickest growth layer, 1955, was formed during a summer of abundant soil moisture and of precipitation double that of the other years. During the year of the thinnest growth layer, 1956, summer soil moisture was scant and the limited winter soil moisture was depleted rather early. In 1957, the year of the next to thinnest growth layer, summer soil moisture was scant and winter soil moisture was depleted a month later than in 1956. Both 1956 and 1957 had low summer precipitation compared with 1955; the winter precipitation of

Table 2.--Temperature, precipitation, and soil moisture as related to growth-layer thickness at Fort Valley and at Walnut Canyon, 1955-58

Growth layers	Year	Average temperature	Precipitation	Soil moisture
		FORT VALLEY		
Thinnest; 0.45 mm. 75 percent of growth layer completed by July 28	1956	Jan.-Apr.--Alternately above and below normal May-June--Above July-Aug.--Below Sept.--Above Strong drying winds in May	Annual: Least in 4-year period, 1955-58 Jan.--Slightly above normal Feb.-May--Much below June--Much above July--Slightly below Aug.--Much below Sept.--Trace Oct.-Dec.--Much below	Began decline in mid-May; near zero by June 20; very low until late July; brief crest first week of August down to 18-inch depth; decline to zero reading early September
Next to thinnest; 0.54 mm. 44 percent of growth layer completed by July 18	1957	Jan.-Mar.--Much above normal Apr.-May--Much below June--Above July-Sept.--Below	Annual: Highest in 4-year period, 1955-58 Jan.--Much above normal Feb.-Apr.--Much below May-June--Much above July--Slightly above Aug.-Sept.--Much below Oct.-Nov.--Much above	Began decline in late June; low by late July; not replenished until October
Next to thickest; 0.64 mm. 16 percent of growth layer completed by July 1	1958	Jan.-Feb.--Above to much above normal Mar.-Apr.--Much below May-June--Above July--Slightly below Aug.--Above Sept.--Below	Annual: Next to highest in 4-year period, 1955-58 Jan.--Much below normal Feb.--Normal Mar.--Much above June-July--Much below Aug.-Sept.--Above Sept.--Nearly 5 times normal	Began gradual decline late May; low by end of June; some recharge began first half of August to be followed by more in September
Thickest; 0.65 mm. 73 percent of growth layer completed by July 23	1955	Jan.-July--Below to much below Aug.--Slightly above Sept.--Slightly below	Annual: Next to least in 4-year period, 1955-58 Jan.--Above normal Feb.--Normal Mar.-May--Below Mar.--Much below June--More than 5 times normal July-Aug.--Above to much above Sept.-Oct.--Much below Nov.--Normal Dec.--Below normal	Abundant all summer
		WALNUT CANYON[1]		
Thinnest; 0.19 mm. 78 percent of growth layer completed by July 25	1956	Alternately above and below normal Jan.--Much above May-June--Above July-Aug.--Below Sept.--Above Strong drying winds in May	Annual: Least in 4-year period, 1955-58 Jan.-May--Below normal Mar.--Much below June--Nearly 5 times normal July-Dec.--Much below	Began decline in late March; zero by late May; recharge at 4-inch depth only, end of June and slightly first week of August; rapid decline to zero in each case
Next to thinnest; 0.49 mm. 74 percent of growth layer completed by July 16	1957	Jan.-Mar.--Much above normal Apr.-May--Below to much below June--Above July-Sept.--Near normal	Annual: Highest in 4-year period, 1955-58 Jan.--Nearly 4 times normal Feb.-Apr.--Below to much below May-June--3 to 4 times normal July-Sept.--Below to much below Oct.-Nov.--Above normal	Began decline in late April; low or zero by July 1; no recorded recharge until late October-early November
Next to thickest; 0.58 mm. 69 percent of growth layer completed by July 14	1958	Jan.-Feb.--Much above normal Mar.-Apr.--Below May-Aug.--Above Sept.--Normal	Annual: Next to highest in 4-year period, 1955-58 Jan.--Much below normal Feb.-Mar.--Much above Apr.-May--Below June--Above July--Much below Aug.-Sept.--Above to much above	At or near zero in mid-June; possibly some recharge to 8-inch depth late August and certainly early September; greater recharge to 12-inch depth late September
Thickest; 0.63 mm. 39 percent of growth layer completed by July 18	1955	Jan.-Feb.--Below to much below Mar.--Slightly above Apr.-July--Below Aug.-Sept.--Above	Annual: Next to least in 4-year period, 1955-58 Jan.--Above normal Feb.-May--Below to much below June-Aug.--Above June--More than 5 times normal Sept.-Oct.--Much below	Became abundant in mid-June to 12-inch depth, and remained so until late August if plaster blocks had reached equilibrium

[1] Because temperature records are not kept at Walnut Canyon and because precipitation records were begun in late 1950, records from Flagstaff Airport are combined here with Walnut Canyon information on tree growth.

1956 was the lowest of the 4 years, whereas that of 1957 was the highest. The year 1958 does not give a very clear picture. It may have been that some plaster blocks had become weakened. Fall-winter precipitation was high; soil moisture penetrated more deeply but decreased earlier than in 1957 and then was replenished early in August.

In summary, temperature variations did not appear to have a direct influence on thickness of growth layers. Information from the 4 years of record suggests that the thickness of a growth layer increased the longer soil moisture remained in good supply going into the early summer and/or the sooner the supply was replenished during the summer.

SUMMARY

Interpretations, with only 4 years of readings, are only indicative. The following points may be mentioned:

1. Available soil moisture fluctuated widely in the root zone; it commonly showed more than one cycle a year, especially at the lower forest border.

2. The records suggest that soil-moisture fluctuations were greater and occurred more rapidly in a dry year and at the drier of the two stations.

3. Infiltration and percolation occurred in a matter of hours and days rather than of weeks and months.

4. Without constant and, in summer, abundant replenishment, soil moisture was removed from the root zone rather rapidly.

5. The soil-moisture regime showed a decided diversity from year to year, and a lack of coincidence in details between the two stations -- one in the forest interior, and the other at the lower border of the ponderosa pine zone.

6. The data and graphs apparently testify to continuous physiological activity that removed soil moisture throughout the year--growth part of the time, transpiration and evaporation all the time.

7. Diameter growth at Walnut Canyon was commonly more advanced than at Fort Valley at any particular time during the growing season.

8. Temperatures within the growing season did not appear to have had a direct and major effect upon amount of tree growth.

9. Of the precipitation periods examined, July-August rainfall seemed to have considerable influence on diameter growth.

10. Thickness of growth layers apparently increased the longer soil moisture remained in good supply going into the early summer and/or the sooner the supply was replenished during the summer.

In general, the study emphasized the desirability of obtaining continuous soil-moisture records for a more extended period, with associated constant check of tree growth.

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able 3.--Percentage of available soil moisture from readings of the Bouyoucos soil-moisture meters, and precipitation recorded at each station, 1955-58

FORT VALLEY

Date	Available soil moisture											Precipitation	
	Depth of meter, in inches											Date	Amount
	4	8	12	18	24	36	48	60	70	84	96		
	Percent												Inches
955													
May 27	74	77	77	75	57	0	0	0	0	3	17	26	0.11
30	72	77	79	76	56	0	0	0	0	2	17		
une 3	63	74	77	73	51	0	0	0	0	2	17	9	T
4	60	73	76	72	47	0	0	0	0	2	17	10	T
13	76	79	77	76	75	0	0	0	0	2	17	13	2.49
14	75	78	77	74	73	0	0	0	0	2	17	14	1.20
15	77	79	77	75	73	0	0	0	0	2	17		
16	77	79	78	75	74	0	0	0	0	2	17		
17	78	79	78	75	74	0	0	0	0	2	17		
21	80	81	80	78	77	10	0	0	0	2	17		
22	81	82	80	79	77	12	0	0	0	2	17		
23	82	82	81	79	77	13	0	0	0	3	17		
24	82	82	81	79	78	17	0	0	0	2	17		
27	82	82	82	80	79	16	0	0	0	2	17		
28	82	82	81	80	79	17	0	0	0	2	17		
29	81	81	81	80	79	17	0	0	0	3	17		
30	81	82	81	80	79	17	0	0	0	3	17		
July 1	81	81	81	80	79	17	0	0	0	3	17		
5	82	82	82	81	79	17	0	0	0	4	17		
6	82	82	82	81	79	17	0	0	0	3	17		
7	81	82	82	82	79	17	0	0	0	3	17		
9	81	82	82	81	77	16	0	0	0	5	17		
12	81	82	82	80	75	15	0	0	0	4	17	13	.03
14	80	82	82	80	73	15	0	0	0	5	17	16	.27
18	83	83	82	80	69	14	0	0	0	5	17	17	.77
19	83	83	82	80	65	13	0	0	0	5	18	18	.15
20	83	83	82	80	63	13	0	0	0	5	18	20	.06
21	83	83	82	79	62	12	0	0	0	5	17	21	.08
22	83	82	82	78	60	12	0	0	0	5	17	22	.03
25	85	84	83	80	55	12	0	0	0	5	18	23	.11
26	85	84	83	81	53	11	0	0	0	5	18	24	.05
27	85	84	82	81	52	11	0	0	0	5	18	25	1.03
28	85	84	83	81	50	11	0	0	0	5	18	26	.16
29	85	84	83	82	49	11	0	0	0	5	18		
												29	.50

WALNUT CANYON

Date	Available soil moisture							Precipitation	
	Depth of meter, in inches							Date	Amount
	4	8	12	18	24	36	42		
	Percent								Inches
31	0	8	9	1	0	0	16	May	.65
3	0	5	6	0	0	0	16		
10	0	4	5	2	0	1	16		
13	83	3	4	1	1	2	16	12	.15
15	89	87	16	1	1	2	16	13	3.05
16	85	88	30	2	1	2	16	14	.18
17	89	89	34	1	1	2	16		
18	90	89	42	1	1	2	16		
19	89	90	47	1	1	2	16		
20	91	91	53	1	1	2	16		
21	91	92	58	1	1	2	16		
22	92	92	63	1	1	2	16		
23	92	92	71	1	1	2	16		
24	90	90	75	1	1	2	16		
25	90	90	78	1	1	3	16		
26	90	91	78	2	1	2	16		
27	89	91	80	2	1	1	16		
28	88	91	80	2	1	1	16		
29	86	90	80	1	1	2	16		
30	84	90	80	-	1	2	16		
1	82	89	80	-	1	2	16		
2	81	89	80	-	1	2	16		
3	74	86	80	-	1	2	16		
4	68	85	77	-	1	2	16		
5	62	84	78	-	0	2	16		
6	56	83	76	-	0	2	16		
7	50	81	75	-	0	2	16		
8	46	79	75	-	0	2	16		
9	40	79	74	-	0	2	16		
10	34	71	72	-	0	2	16		
11	28	66	70	-	0	2	16		
12	23	64	67	4	0	2	16		
13	18	59	64	5	0	2	16		
14	17	56	60	5	0	2	16		
15	18	61	58	5	0	4	16	15	1.29
16	41	81	71	5	2	2	16	16	.25
17	61	87	78	5	0	2	16	17	.46
18	85	90	82	7	1	2	17		
19	85	90	84	7	1	2	17		
20	86	91	85	8	1	2	17	20	.08
21	87	92	85	9	1	2	17		
22	88	92	85	10	1	2	17	22	.01
23	88	92	85	10	1	2	17	23	.06
24	85	91	85	11	1	2	17	24	.20
25	35	90	85	11	1	2	17	25	.27

Table 3.--Percentage of available soil moisture from readings of the Bouyoucos soil-moisture meters, and precipitation recorded at each station, 1955-58 (continued)

FORT VALLEY

Date		Available soil moisture											Precipitation	
		Depth of meter, in inches											Date	Amount
		4	8	12	18	24	36	48	60	70	84	96		
		Percent												Inches
1955 July (cont'd)														
Aug.	1	85	84	83	81	45	10	0	0	0	5	18	1	.11
													2	T
	3	87	86	85	82	44	10	0	0	0	5	18	3	.51
	4	86	85	84	82	42	10	0	0	0	5	18	4	.03
	5	86	85	84	81	40	10	0	0	0	5	18		
													6	.07
													7	.25
	8	87	86	84	80	36	9	0	0	0	5	18	8	.42
	9	88	86	85	83	35	9	0	0	0	5	18	9	.57
	10	87	86	85	83	33	9	0	0	0	5	18	10	.12
	11	88	87	85	83	32	9	0	0	0	5	18	11	.44
	12	88	87	85	82	31	9	0	0	0	5	18	12	T
													13	.64
	15	88	87	85	83	29	8	0	0	0	6	18	15	1.14
	16	89	87	85	83	36	8	0	0	0	5	18	16	.01
	17	89	87	85	83	79	7	0	0	0	5	18	17	.94
	18	89	87	85	83	80	7	0	0	0	5	18		
	19	89	87	85	83	80	6	0	0	0	5	18		
													20	.52
													21	T
	22	89	87	85	83	82	8	0	0	0	5	18		
	23	89	87	85	83	82	10	0	0	0	5	18		
	24	89	80	85	84	82	10	0	0	0	5	18	24	1.28
	25	89	82	85	83	82	76	0	0	0	5	19		
	26	89	80	85	83	82	77	0	0	0	5	19		
	29	89	87	84	83	82	80	0	0	0	5	19		
	30	89	86	82	84	82	80	0	0	0	5	19		
	31	89	87	81	84	82	80	0	0	0	5	19		
Sept.	1	89	88	76	84	82	81	0	0	0	5	19		
	2	89	87	76	84	82	81	0	0	0	5	19		
	7	87	86	85	84	82	82	0	0	0	6	19		
	9	87	86	84	84	82	82	2	0	0	6	19		
	12	86	86	83	84	82	81	3	0	0	6	19		
	16	85	85	81	83	82	77	4	0	0	6	19		
													17	T
	19	84	85	82	84	82	70	3	0	0	6	19		
	23	82	84	60	83	81	58	3	0	0	6	19		
Oct.													4	.04
	10	40	49	55	58	49	18	0	0	0	5	19	10	.05
	19	22	30	42	38	20	11	0	0	0	4	19		
	24	17	20	30	21	15	7	0	0	0	3	19		
Nov.													13	.18
													14	.19
													15	.42
													16	T
													18	.26
													22	.27
Dec.													2	.90
													3	.15
													4	.10
													7	T

WALNUT CANYON

Date		Available soil moisture							Precipitation	
		Depth of meter, in inches							Date	Amount
		4	8	12	18	24	36	42		
		Percent								Inches
1955 July (cont'd)	26	88	90	85	11	1	2	17		
	27	88	90	84	12	1	2	17		
	28	89	90	83	12	1	2	17		
	29	87	89	84	12	1	2	17	29	.01
	30	85	89	82	12	1	2	17	30	.26
	31	85	88	82	12	1	2	17	31	.09
Aug.	1	84	87	82	13	1	2	17		
	2	83	85	81	13	1	2	17		
	3	81	84	80	13	1	3	17	3	.05
	4	78	83	78	13	1	3	17	4	.01
	5	72	81	75	13	1	3	17	5	.26
	6	66	78	72	13	1	3	17	6	.98
	7	81	82	72	13	1	3	17	7	.63
	8	89	91	75	13	1	3	17	8	.25
	9	90	92	79	13	1	3	17		
	10	91	94	82	13	1	3	17		
	11	91	94	83	13	1	3	17		
	12	91	95	85	13	1	3	18	12	.29
	13	92	94	85	13	1	3	17		
	14	92	95	85	13	1	4	18	14	.02
	15	93	95	85	13	1	4	18		
	16	92	95	86	14	1	4	18	16	.14
	17	93	95	85	14	1	4	18		
	18	92	95	85	14	1	4	18		
	19	90	93	84	14	1	4	18	19	.28
	20	87	90	82	15	2	4	18		
	21	92	95	85	15	2	4	18		
	22	92	95	85	14	2	4	18		
	23	91	95	85	14	2	4	18	23	.04
	24	91	94	84	14	2	4	18	24	.16
	25	90	94	84	14	2	4	18		
	26	88	92	83	14	2	4	18		
	27	84	91	82	14	2	4	18	27	.06
	28	80	89	81	14	2	4	18	28	.01
	29	74	86	78	14	2	4	18		
	30	65	81	73	14	3	5	19		
	31	59	78	69	14	3	5	19		
Sept.	2	45	67	57	13	4	5	18		
	4	28	55	47	13	4	5	19		
	5	20	49	41	13	4	5	19	5	.07
	6	18	43	32	11	4	5	19		
	7	15	37	25	11	4	5	19		
	8	12	31	23	10	4	5	19		
	9	11	25	19	10	4	5	19		
	10	10	20	15	10	3	5	18		
	11	8	18	13	8	3	5	18		
	13	5	15	9	7	4	5	18		
	14	3	13	6	6	3	5	18		
	22	1	1	1	2	2	4	17		
	29	0	0	0	1	1	4	15		
Oct.									4	.05
	8	0	0	0	0	1	4	13		
	13	0	0	0	0	1	4	12		
	20	0	0	0	0	1	3	10		
	28	0	0	0	0	0	3	8		
Nov.	4	0	0	0	0	0	3	7		
	13	0	0	0	0	0	3	7	13	.62
									14	.33
	15	1	-	-	-	-	3	7	15	.02
									22	.28
	24	41	0	0	0	0	3	9		
Dec.	1	55	0	0	0	0	3	10		
									2	.98
	29	76	37	1	0	0	4	11		

able 3.--Percentage of available soil moisture from readings of the Bouyoucos soil-moisture meters, and precipitation recorded at each station, 1955-58 (continued)

FORT VALLEY | WALNUT CANYON

Date	Available soil moisture											Precipitation		Date	Available soil moisture							Precipitation	
	Depth of meter, in inches											Date	Amount		Depth of meter, in inches							Date	Amount
	4	8	12	18	24	36	48	60	70	84	96				4	8	12	18	24	36	42		
	Percent												Inches		Percent								Inches
956																							
an.												16	T	16	52	39	0	0	0	3	11	16	.10
												17	.48									17	.06
												20	.05									20	.01
												21	.25									21	.13
												22	T	22	45	33	1	0	0	1	10	22	T
												23	T									23	.10
												24	.22	25	45	31	1	0	0	2	11	25	.05
												25	T									26	.06
												26	.05									27	.20
												27	.38	28	48	30	1	0	0	1	10	28	.30
												29	.45									29	.23
												29	.62									31	.23
Feb.												1	.22									1	.02
												7	T									8	T
												8	.40									9	.83
												9	.04									16	.31
												16	.10	18	78	59	2	0	0	1	12		
												17	.20									23	.01
												19	T	29	80	81	27	0	0	2	12		
												24	.04										
Mar.												7	.09	2	81	82	35	0	0	2	12		
												12	.30	3	81	82	38	0	0	2	12		
												13	.08	5	84	84	46	0	0	2	12	6	.02
												15	T	7	83	84	50	0	0	2	12	7	T
30	75	73	61	71	66	9	0	0	0	2	14			9	81	83	55	1	0	2	12		
														10	82	84	58	0	0	2	12	11	.05
														12	82	85	64	0	0	2	12	12	.24
														13	81	83	64	0	0	2	12	14	.01
														15	81	83	66	0	0	2	12		
														16	82	83	69	0	0	2	12		
														17	80	82	71	0	0	2	13		
														18	83	84	72	0	0	2	13		
														24	82	85	75	0	0	2	13		
														26	83	84	75	0	0	2	13		
														30	76	82	73	0	0	2	13		
Apr.												1	.05	1	67	79	71	0	0	2	13	1	.01
6	77	75	62	72	64	7	0	0	0	0	14	2	.10	6	60	68	64	0	0	2	14	2	.05
13	77	75	62	72	60	5	0	0	0	0	14	13	.12	7	54	65	63	0	0	2	14		
												14	.30	8	53	63	61	0	0	3	14		
												16	T	9	49	61	60	0	0	3	14		
												17	.20	11	43	57	57	0	0	3	14	14	.37
												18	T	16	29	47	47	0	0	4	13	15	.14
20	77	75	62	69	54	4	0	0	0	2	15	19	.27	17	26	45	45	0	0	4	13	17	T
												21	.08	20	28	39	38	0	0	5	14	18	.26
												26	T	21	28	38	38	0	0	5	14	20	.04
27	79	77	63	68	50	3	0	0	0	2	15	27	T	22	29	36	35	0	0	5	14		
														23	30	36	33	0	0	4	14		
														24	28	34	31	0	0	5	14		
														25	28	33	28	0	0	5	15		
														26	26	35	26	0	0	5	15		
														28	23	38	20	0	0	5	14	27	.05
														29	22	29	17	0	0	5	14		
														30	21	26	17	0	0	5	15		
May 4	80	78	63	66	46	2	0	0	0	2	15			1	20	23	16	0	0	4	15		
11	80	76	61	62	39	2	0	0	0	2	16			2	18	21	15	0	0	4	15		
14	79	76	60	59	35	2	0	0	0	3	16			3	17	20	15	0	0	4	15		
												20	.06	5	13	17	11	0	0	4	14		
												21	T	6	12	17	11	0	0	4	14		
												22	.11	7	11	16	10	0	0	4	14		
25	74	68	60	46	18	0	0	0	0	2	15			9	6	13	6	0	0	4	14		
														15	0	4	1	0	0	4	12		
														22	0	0	0	0	0	2	12	19	.12
														29	0	0	0	0	0	1	9		
June 1	57	50	50	32	11	0	0	0	0	2	16			6	0	0	0	0	0	1	6		
8	37	29	37	16	6	0	0	0	0	2	15			12	0	0	0	0	0	1	5		
15	17	13	16	6	2	0	0	0	0	2	15			20	0	0	0	0	0	1	4		

Table 3.--Percentage of available soil moisture from readings of the Bouyoucos soil-moisture meters, and precipitation recorded at each station, 1955-58 (continued)

FORT VALLEY														WALNUT CANYON									
Date	Available soil moisture											Precipitation		Date	Available soil moisture							Precipitation	
	Depth of meter, in inches											Date	Amount		Depth of meter, in inches							Date	Amount
	4	8	12	18	24	36	48	60	70	84	96				4	8	12	18	24	36	42		
1956	Percent												Inches		Percent								Inches
June 22	6	6	3	0	0	0	0	0	0	0	14	28	.24	27	0	0	0	0	0	1	3	28	.17
(cont'd) 29	4	4	2	0	0	0	0	0	0	0	14	30	1.65	30	20	0	0	0	0	1	3	29-30	1.27
July 3	22	12	2	0	0	0	0	0	0	0	13	1	T	2	75	0	0	0	0	1	5		
5	22	13	3	0	0	0	0	0	0	0	13			3	65	0	0	0	0	1	5		
6	23	14	5	0	0	0	0	0	0	0	14			4	62	0	0	0	0	1	5		
9	20	15	4	0	0	0	0	0	0	0	14			5	59	0	0	0	0	0	6		
10	20	14	4	0	0	0	0	0	0	0	13			6	57	0	0	0	0	0	6		
11	19	14	4	0	0	0	0	0	0	0	13			7	53	0	0	0	0	1	6		
12	19	14	3	0	0	0	0	0	0	0	13	12	T	8	49	0	0	0	0	1	6		
13	18	13	3	0	0	0	0	0	0	0	13	13	.20	10	40	0	0	0	0	1	5	12-13	.24
												14	T	14	12	0	0	0	0	1	4	14	.30
												15	T	15	10	0	0	0	0	1	4		
16	17	11	2	0	0	0	0	0	0	0	13	16	.07	17	4	0	0	0	0	1	3		
17	16	11	2	0	0	0	0	0	0	0	13	18	.13	19	3	0	0	0	0	0	3	19	.02
18	12	10	2	0	0	0	0	0	0	0	13	19	.32	21	1	0	0	0	0	0	3	21	.42
19	14	9	0	0	0	0	0	0	0	0	13	20	T	22	1	0	0	0	0	1	3		
20	13	9	2	0	0	0	0	0	0	0	13	21	.12	24	2	0	0	0	0	0	3		
												22	.20	25	2	0	0	0	0	0	3		
												23	T	26	2	0	0	0	0	0	3	26	.24
23	11	8	0	0	0	0	0	0	0	0	13	25	.23	28	6	0	0	0	0	0	5	27	.57
24	11	7	0	0	0	0	0	0	0	0	13	26	.49	29	11	0	0	0	0	0	6	28	T
26	9	5	0	0	0	0	0	0	0	0	12	27	T	30	12	0	0	0	0	0	8	29	.23
30	75	34	72	65	0	0	0	0	0	0	12	28	.07									30	.13
31	76	43	72	69	0	0	0	0	0	0	12	29	.69										
												30	.09										
Aug. 2	79	48	71	66	0	0	0	0	0	0	12	2	.38									1	.32
4	36	47	42	6	0	0	0	0	0	0	12	11	T	4	22	0	0	0	0	0	8	11	.30
6	74	51	67	57	0	0	0	0	0	0	12	12	.12	13	9	0	0	0	0	0	4	14	.15
9	68	51	62	49	0	0	0	0	0	0	12	13	.44	15	3	0	0	0	0	0	4	15	.07
13	55	50	55	37	0	0	0	0	0	0	12	14	.16	17	1	0	0	0	0	0	4	17	.16
16	48	47	50	24	0	0	0	0	0	0	12	15	.20									21	.19
												16	.02	24	0	0	0	0	0	0	2	24	.04
20	46	50	49	13	0	0	0	0	0	0	12	17	.28										
												18	.05										
22	42	49	42	10	0	0	0	0	0	0	12	19	.04										
28	19	38	29	2	0	0	0	0	0	0	12	22	.11										
31	13	22	16	0	0	0	0	0	0	0	12	23	T										
Sept. 4	7	12	4	0	0	0	0	0	0	0	12			6	0	0	0	0	0	0	0	30	T
7	3	6	0	0	0	0	0	0	0	0	12												
14	0	2	0	0	0	0	0	0	0	0	12												
21	0	0	0	0	0	0	0	0	0	0	12												
28	0	0	0	0	0	0	0	0	0	0	12	29	T										
Oct.												2	.03	4	0	0	0	0	0	0	0		
												3	.16	23	0	0	0	0	0	0	0	24	.29
8	0	0	0	0	0	0	0	0	0	0	11	7	.09	30	0	0	0	0	0	0	0	29	.09
12	0	0	0	0	0	0	0	0	0	0	11	24	.17										
19	0	0	0	0	0	0	0	0	0	0	11	29	.37										
Nov. 16	0	0	0	0	0	0	0	0	0	0	9	1	.05										
23	0	0	0	0	0	0	0	0	0	0	10	2	T										
30	0	0	0	0	0	0	0	0	0	0	9												
Dec. 7	0	0	0	0	0	0	0	0	0	0	8	5	T	13	0	0	0	0	0	0	0	7	.42
14	0	0	0	0	0	0	0	0	0	0	8	7	.13										
21	0	0	0	0	0	0	0	0	0	0	8	8	.41										
1957																							
Jan.												4	.20	7	0	0	0	0	0	0	0	5	.42
5	0	0	0	0	0	0	0	0	0	0	7	5	.31	9	75	0	0	0	0	0	0	7	.03
												6	.13	10	75	0	0	0	0	0	0	8	1.72
												8	1.28	12	75	22	0	0	0	0	0	9	.88
												9	.69	13	77	35	0	0	0	0	0	13	.13
												10	.16	15	77	58	11	0	0	0	0		
11	64	63	53	63	0	0	0	0	0	0	6	11	.23	16	75	74	14	0	0	0	0		
												13	T	18	75	75	22	0	0	0	0		
												14	.39									21	.50
18	69	67	58	68	45	0	0	0	0	0	6	21	.23									25	.40
												22	.11									26	.60

able 3.--Percentage of available soil moisture from readings of the Bouyoucos soil-moisture meters, and precipitation recorded at each station, 1955-58 (continued)

FORT VALLEY															WALNUT CANYON									
Date		Available soil moisture											Precipitation		Date	Available soil moisture							Precipitation	
		Depth of meter, in inches											Date	Amount		Depth of meter, in inches							Date	Amount
		4	8	12	18	24	36	48	60	70	84	96				4	8	12	18	24	36	42		
957		Percent												Inches		Percent								Inches
													24	T									27	1.31
n.	25	70	68	55	69	58	0	0	0	0	0	6	25	.07									28	.52
ont'd)													26	.34									29	.02
													27	.87									30	.40
													28	.60										
													29	.24										
													30	.32										
													31	T										
eb.	18	72	71	63	70	65	64	0	0	0	0	7	18	.18	5	85	86	86	0	0	0	0		
													19	.17	8	85	86	86	0	0	0	0		
													20	.09	11	86	85	87	75	76	1	0		
													21	.02	14	86	85	84	80	80	75	5		
													22	T	19	82	85	85	82	82	76	9	18	.24
	25	73	72	54	71	70	68	52	0	0	0	8	24	.60	23	82	85	85	84	84	79	12	19	.02
															28	82	86	85	84	85	78	23	23	.25
ar.													1	.14									1	.94
													2	.52	3	82	85	85	85	85	76	32		
													3	.04	6	82	85	85	85	85	78	38		
	4	74	72	64	72	71	71	58	0	0	0	8	4	T	10	82	85	86	85	85	78	45		
													6	.04	14	82	85	85	85	85	80	48		
	11	75	73	62	72	72	71	61	0	0	0	9	10	.05	18	82	85	85	85	85	80	52	17	T
	18	75	73	65	73	67	72	62	0	0	0	8	17	.26	21	82	86	86	86	86	78	55	19	.07
													20	.13	28	72	96	85	85	85	76	56	20	.55
													21	.05	31	82	86	86	85	85	75	57	22	.10
													22	.08										
	25	74	71	63	72	71	72	61	3	0	0	10	31	T										
or.	5	75	72	64	72	71	72	61	5	0	0	9	2	.22									2	.29
	12	77	73	65	74	72	73	61	6	0	0	10	3	.19	11	82	85	85	85	85	72	55		
	19	76	73	64	74	72	72	60	7	0	0	10	19	T	18	75	81	85	85	85	68	55		
													22	.17	23	62	70	80	80	82	65	55	22	.34
													23	.27	28	56	60	71	78	80	60	52		
													24	.11										
													25	.06										
	26	76	70	64	73	72	72	58	6	0	0	10	26	T										
ay	6	78	73	65	74	72	73	54	5	0	0	10	7	.27	5	42	48	56	72	76	56	52	6	.10
													11	.29									7	.26
													12	.38	10	27	35	45	67	75	52	52	10	.03
	13	78	74	64	74	73	73	51	4	0	0	11	13	.04									11	.45
													15	.11									12	.37
													16	.16									13	.02
													17	T									14	.26
													18	T									19	.25
													19	T	21	55	35	32	55	64	46	49	21	.14
	20	79	73	63	74	72	73	47	4	0	0	11	20	.45									23	.14
													21	.10	31	62	36	25	46	60	41	47		
													22	.14										
													23	.05										
	27	78	74	63	74	73	73	44	4	0	0	11	24	.13										
ne	3	81	77	63	75	75	75	40	4	0	T	12	5	T									10	1.00
													6	.02									11	.10
	11	81	78	62	72	74	73	34	3	0	T	11	10	.36	12	29	15	12	36	50	32	45		
	17	85	82	66	75	79	78	31	6	T	4	13	11	.85	24	17	12	9	23	41	26	38		
	24	85	82	60	71	75	6	26	5	T	4	13	26	.11										
ly	1	72	74	56	62	69	7	21	6	2	5	13	5	T	1	2	5	4	15	32	21	33	7	T
													6	.02	8	0	T	T	11	22	17	28	8	.20
													7	.03									9	.35
	8	44	53	42	52	61	7	17	6	1	5	14	9	.02	10	0	T	T	10	19	17	28	10	.02
													10	T	16	0	0	T	5	13	13	22	17	.15
													14	.48	19	0	0	T	4	12	12	20	19	.18
	16	16	27	26	29	41	7	13	6	2	5	13	16	.02	23	0	0	0	2	11	11	17		
													17	.20									26	.25
													18	.57	30	0	0	0	T	8	9	15	27	.10
	19	14	26	26	20	31	7	12	5	2	6	13	19	.11										
													20	.36										
	22	15	27	19	15	20	7	12	5	2	5	13	24	.11										
													25	.04										

Table 3.--Percentage of available soil moisture from readings of the Bouyoucos soil-moisture meters, and precipitation recorded at each station, 1955-58 (continued)

FORT VALLEY															WALNUT CANYON									
		Available soil moisture											Precipitation			Available soil moisture							Precipitation	
Date		Depth of meter, in inches											Date	Amount	Date	Depth of meter, in inches							Date	Amount
		4	8	12	18	24	36	48	60	70	84	96				4	8	12	18	24	36	42		
1957		Percent												Inches		Percent								Inches
July	26	14	21	13	12	14	6	11	4	2	5	13	26	.37										
(cont'd)													27	.31										
													28	.05										
	29	16	19	13	11	13	5	10	5	2	5	15	29	.16										
Aug.													3	.42									4	.43
													4	.03									5	.18
	5	13	0	42	8	9	5	7	4	2	5	13	5	.30	6	0	0	0	0	4	6	14	6	.06
													6	.45	8	1	0	0	0	4	6	13		
													11	.10	13	0	0	0	0	T	5	12	10	.05
	13	15	17	27	5	6	4	5	4	T	5	14	13	.02									15	.21
													14	T	20	0	0	0	0	0	3	12	24	.64
													19	T									25	.03
	20	8	10	5	3	4	2	4	2	T	4	11	20	.09									26	.26
													25	.45	27	0	0	0	0	T	3	11	27	.03
													26	.16									29	.05
	27	17	0	3	1	1	1	4	3	T	4	14	27	.22									30	.21
													29	.07										
													30	.09										
													31	.02										
Sept.	5	7	0	T	0	0	0	T	T	0	2	14			4	0	0	0	0	0	3	12		
	11	T	0	0	0	0	T	T	T	T	4	14	10	T	9	0	0	0	0	0	4	7		
	17	0	0	0	T	T	T	2	2	T	4	15			16	0	0	0	0	T	5	7		
	23	0	0	0	0	0	T	2	T	T	3	15			23	0	0	0	0	0	5	6		
															30	0	0	0	0	0	3	5		
Oct.	2	0	0	0	0	0	T	T	T	T	3	13	11	.55	7	0	0	0	0	0	T	3		
	7	0	0	0	0	0	0	0	0	0	T	11	12	.57									11	.27
													13	.71									12	1.23
	14	76	33	59	81	0	0	0	0	0	0	9	14	.12	14	0	0	0	0	0	3	9		
													15	.03	16	7	0	0	0	0	3	11		
	16	76	37	58	80	0	0	0	0	0	T	10	16	.03	18	14	0	0	0	0	3	13		
													17	T									19	.24
													20	.19									20	.20
	21	70	38	56	70	0	0	0	0	0	0	8	21	.22	21	18	0	0	0	0	3	14	21	.22
													22	.65	25	29	0	0	0	0	4	14		
	28	81	46	77	66	0	0	0	0	0	T	7	28	T									28	.29
													29	.29	29	36	0	0	0	0	4	14	29	.03
	31	83	0	80	64	0	0	0	0	0	0	9	31	.60									31	1.10
Nov.													1	.39	1	53	0	0	0	0	4	14	1	.21
													2	.13									2	.28
													3	1.26									3	.94
	4	83	53	81	79	81	0	0	0	0	0	8	4	.80	4	80	80	80	0	0	3	14	4	.28
													5	T									6	.19
													6	.38	7	76	82	81	0	0	4	15		
													7	.08	15	79	84	83	84	33	6	15		
													12	.03									16	.30
													15	T	20	76	83	83	85	81	5	16		
													16	.52										
													17	.22										
													22	T										
Dec.	3	80	0	77	79	79	8	0	0	0	0	9	5	.12	3	74	82	83	86	83	4	15		
													6	.30									5	.15
													16	.36	10	75	82	84	85	84	8	16		
													17	T									15	.08
													18	.04									18	.10
													19	.03	24	74	82	83	84	83	17	16		
1958																								
Jan.													3	T									3	.13
													4	.03	17	72	80	80	82	81	20	16		
													5	T									27	.15
													11	T										
	14	76	71	75	76	75	7	T	T	2	3	10	14	T										
													19	T										
													20	T										
													22	.03										
													25	.04										
													27	.32										

Table 3.--Percentage of available soil moisture from readings of the Bouyoucos soil-moisture meters, and precipitation recorded at each station, 1955-58 (continued)

FORT VALLEY														WALNUT CANYON									
Available soil moisture												Precipitation		Available soil moisture								Precipitation	
Date	Depth of meter, in inches											Date	Amount	Date	Depth of meter, in inches							Date	Amount
	4	8	12	18	24	36	48	60	70	84	96				4	8	12	18	24	36	42		
958	Percent												Inches		Percent								Inches
an. (cont'd)												31	T										
Feb.												4	.53									3	.12
												5	1.00									4	1.12
												6	T									5	.02
												9	T									9	.01
												10	.05	12	73	81	82	83	80	20	17		
												13	T									13	.05
												14	.13									20	.06
												21	.09									23	.13
												23	T									25	.56
												24	.10									26	.06
												26	.73										
												27	T										
Mar.												2	T									3	.26
												3	T									4	.05
												4	.18									6	.10
												5	T									7	.28
												6	.04									9	.20
												7	.68									11	.05
												9	.30									12	.02
												11	T									13	.16
												12	.21									16	.17
												13	.15									17	.22
												14	.12									22	.88
												16	.32									28	.29
												17	.56										
												18	.04										
												21	T										
												22	.75										
												23	.33										
												24	T										
												25	T										
												28	.34										
												29	.08										
Apr.												2	.68									2	.44
												3	T									3	.10
												4	.54									4	.66
												5	.30									5	.14
												7	T									7	T
												8	.08									8	.10
												9	T										
28	74	70	54	71	72	10	68	69	70	73	76	17	.13										
May												3	.25									2	.03
5	81	76	79	78	76	7	74	81	75	79	83	11	.11									11	.43
												12	.33									30	T
21	75	72	68	75	74	10	70	70	70	74	77	21	.10										
												31	.06										
June 12	48	43	40	65	73	13	68	70	70	75	79	16	T	17	0	0	0	0	24	20	58		
												22	.38									21	.20
26	15	14	10	44	62	10	62	65	70	76	80	23	T	23	0	0	0	0	12	12	50		
												30	T										
July 14	10	5	6	12	15	10	45	55	63	74	80	18	T	7	0	0	0	0	1	6	20	6	.04
												23	T	17	0	0	0	0	0	3	10		
												24	.58									23	.17
												25	T									24	.03
												26	.08									25	.01
												27	.06									26	.09
												28	.03									29	.26
												29	T	31	0	0	0	0	0	0	5	30	.10
												30	.15										
												31	.02										
Aug.												2	T									2	.03
												3	.22									3	.17
4	5	2	2	3	5	6	18	28	43	72	77	4	.06									4	.07

Table 3.--Percentage of available soil moisture from readings of the Bouyoucos soil-moisture meters, and precipitation recorded at each station, 1955-58 (continued)

FORT VALLEY															WALNUT CANYON									
Available soil moisture													Precipitation		Available soil moisture								Precipitation	
Date	Depth of meter, in inches												Date	Amount	Date	Depth of meter, in inches							Date	Amount
	4	8	12	18	24	36	48	60	70	84	96					4	8	12	18	24	36	42		
1958	Percent													Inches		Percent								Inches
Aug. (cont'd)													5	.11									5	.40
													6	.54									6	.03
													7	.31	8	0	0	0	0	0	0	12	7	.16
													10	.49									11	.27
11	15	14	56	67	10	8	14	21	37	66	76		11	.16									13	.04
													13	.07									17	1.56
													14	.01									19	.09
													15	.02									21	.55
													17	.75									22	.05
18	17	18	42	58	8	8	12	17	31	63	72		18	.02									27	.11
													19	.01									29	.02
													20	.06										
													21	.35										
													22	.04										
													23	T										
25	24	27	56	69	9	8	12	16	27	62	75		24	.70										
													28	.16										
													29	T										
													30	.01										
Sept.													1	T									1	.07
2	30	32	48	67	9	7	11	15	24	62	73		3	T									2	.32
													4	1.73									3	.29
													5	.32	5	56	28	3	0	0	8	12	4	.47
													7	.04									7	.05
8	31	34	55	67	66	6	10	14	21	56	64		8	1.15									8	.20
													9	T									11	.14
													10	1.38									12	1.03
													12	.27									13	.23
15	65	62	55	64	63	12	37	14	20	54	61		13	.69									14	.04
22	72	74	65	74	74	12	48	15	20	58	71		23	.65	23	70	56	12	0	0	10	12	23	.16
													24	.28									24	.63
													25	.09									26	.08
													27	.61									27	.84
													28	.66									28	.79
29	72	77	64	69	70	50	44	16	20	54	71		29	.48	29	82	89	85	0	0	9	15	29	.42
Oct. 6	67	66	65	67	64	51	48	15	18	51	62		6	.20	2	82	90	85	0	0	10	15	5	.07
													12	.16	8	82	90	88	10	1	10	13	10	.29
13	77	77	75	79	77	55	50	16	18	56	72		13	T	15	81	85	88	12	2	9	13	23	.02
21	70	66	57	73	72	51	42	14	18	53	68		24	.07	20	70	72	80	12	4	9	13	24	.19
													25	.32									25	.20
27	61	60	52	64	63	42	33	14	17	49	63		26	T									29	.15
													30	.02									30	.11
Nov.													11	T	4	51	38	53	12	4	9	17		
12	56	53	47	57	52	18	18	13	17	49	69		12	.58	11	45	25	42	9	2	9	18	11	T
													16	.50									12	.25
													17	.24									15	.15
													24	T									16	.82
													27	.06									17	T
Dec.															13	55	52	28	4	4	8	18		
													29	.05	16	53	50	25	2	2	8	18	28	.02

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Glock, Waldo S., Gaines, Edward M., and Agerter, Sharlene R. 1964. Soil-moisture fluctuations under two ponderosa pine stands in northern Arizona. U. S. Forest Serv. Res. Paper RM-9, 34 pp., illus.

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NEW PRODUCTS

FROM LOW-GRADE PONDEROSA PINE TIMBER

U. S. FOREST SERVICE RESEARCH PAPER RM-10, DECEMBER 1964

ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION
and
FOREST PRODUCTS LABORATORY
FOREST SERVICE U. S. DEPARTMENT OF AGRICULTURE

Acknowledgments

This study was made at the U.S. Forest Products Laboratory, Madison, Wisconsin, through collaboration of personnel of the Forest Products Laboratory, the Rocky Mountain Forest and Range Experiment Station, the Southwestern Regional Office of the Forest Service, and the Southwest Pine Association (affiliated with Western Pine Association).

Lincoln A. Mueller of the Rocky Mountain Station participated in the study. The industry representative most directly concerned with the work was A. C. Hunt of Southwest Forest Industries, Inc., who served as chairman of the industry liaison committee.

Forest Products Laboratory scientists bearing primary responsibility for specific phases of the program included:

Bruce G. Heebink, and John F. Lutz on initial survey, planning, scheduling, and coordination;

Bruce G. Heebink and Charles J. Gatchell on product engineering and design, overlaid products, particle board products, and specialized flooring products;

Richard F. Blomquist, Robert A. Hann, John F. Lutz, Chester Roessler, and M. L. Selbo on glues and glued products; and

Fred Werren, Edward W. Kuenzi, and Billy Bohannon on engineering tests and evaluation.

In addition, the advice and opinion of numerous other Forest Service scientists contributed significantly to the direction and development of the study.

. Forest Service Research Paper RM-10 December 1964

NEW PRODUCTS FROM LOW-GRADE PONDEROSA PINE TIMBER

by

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Forest Products Laboratory[2]

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[1] Central headquarters maintained in cooperation with Colorado State ersity at Fort Collins; author is located at Flagstaff in cooperation with ona State College.

[2] Forest Service, U. S. Department of Agriculture, Madison, Wisconsin. or is now Director, Division of Forest Products and Engineering Research, est Service, U. S. Department of Agriculture, Washington, D. C.

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New Products from Low-Grade Ponderosa Pine Timber

by
Roland L. Barger and Herbert O. Fleischer

THE STUDY IN BRIEF

Low-quality ponderosa pine sawtimber poses severe economic problems for wood-product industries of the Southwest. Much of the material currently available is unsuited to the production of salable grades of lumber, historically the major product manufactured. Efficient utilization of the resource requires that this material be diverted to more suitable uses. A declining lumber market has further emphasized the need for product diversification in the region.

An intensive program of product research and development was proposed after a field survey and analysis of the problem in 1961. The program placed primary emphasis upon developing profitable uses for low-grade ponderosa pine timber. Products specifically suggested for evaluation included underlayment plywood, glue-laminated beams, overlaid siding, flooring, and particle board.

Product design, development, and evaluation studies were initiated at the Forest Products Laboratory in 1962, and were essentially completed in 1963. The research program has developed an array of light-construction products that can feasibly be produced from low-grade ponderosa pine timber. These products can be used individually in conventional construction, or can be combined as the integral components of a coordinated component building system.

This study deals specifically and in detail with the technical aspects of production--not with economic aspects. Technical feasibility alone is often not an adequate criterion for decision. It must be supplemented with economic evaluations of investment and production costs and of marketing opportunities. Some work in developing supplementary economic information is to be started in the near future. It should be recognized, however, that many economic considerations are peculiar to a particular firm or area, and not common to the industry as a whole. Consequently, a firm can perhaps benefit most from its own analysis of economic feasibility.

THE SOUTHWESTERN TIMBER RESOURCE

Ponderosa pine is an important commercial timber species in many western states. It is the major commercial species in the Southwestern region. Arizona and New Mexico contain almost 10 million acres of commercial forest land, supporting approximately 60 billion board feet of sawtimber (fig. 1). Ponderosa pine accounts for more than two-thirds of this volume (table 1).

Much of the ponderosa pine timber in the Southwest is in cutover stands, often exists under marginal growth conditions, and is of low quality for many conventional uses. Sawtimber currently available in the region characteristically includes high proportions of grade 5 and lower quality logs (fig. 2). A summary of cruise data from five recent southwestern timber sales indicates that over 80 percent of the logs offered for sale are of grades 4, 5, and 6 (table 2).[3]

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[3] *Grades 4, 5, and 6 refer to those of the six-grade ponderosa pine log grading system developed by Pacific Northwest Forest and Range Experiment Station (PNW), Portland, Oregon.*

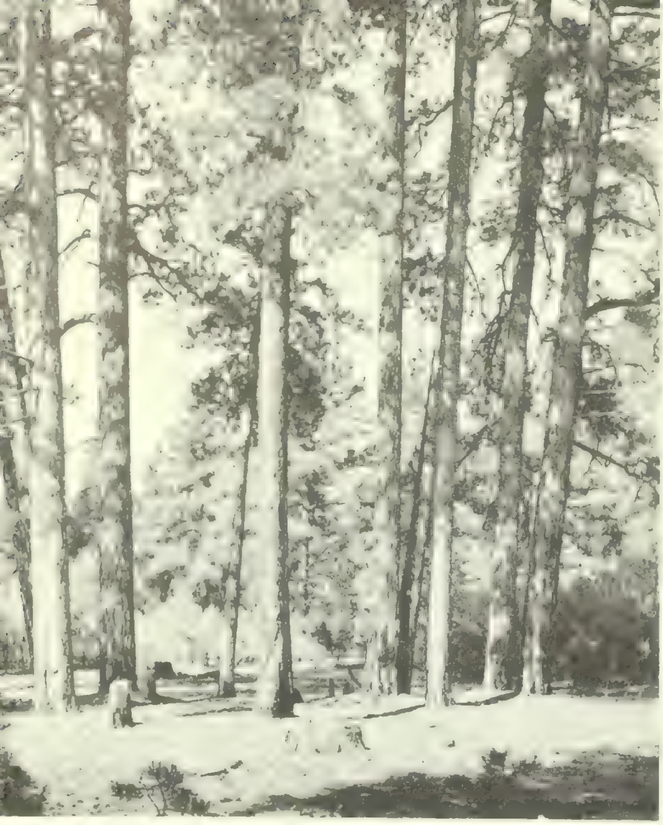

Figure 1.--Typical southwestern ponderosa pine sawtimber stand. Note heavy limbing characteristic of the species. Coconino National Forest, Arizona.

Most of the logs included in the "grade 4 and lower" category are of grades 5 and 6. Grade 4 logs are extremely rare in southwestern ponderosa pine forests because of the gap in the age class in trees that commonly yield grade 4 logs. When present, such trees are generally reserved for future cutting.

For most conventional products, knots are the primary limiting defect in southwestern ponderosa pine. Ponderosa pine tends to be somewhat open-grown and does not prune well naturally; consequently, most stems have numerous large, live limbs. The resulting log knots are generally firmly intergrown and do not loosen in the production of lumber. Most of these knots have large areas of short grain or irregular end grain associated with them, however, which potentially affect the strength of the entire piece. Dead, encased, and infirm knots are relatively rare in ponderosa pine, and are quite small when they do occur.

Table 1.--Volume of commercial sawtimber in the southwestern region

Species	State		Total
	Arizona	New Mexico	
	MM board feet		
Ponderosa pine	23,751	18,177	41,928
Douglas-fir	2,130	4,883	7,013
True firs	1,203	2,603	3,806
Engelmann spruce	778	3,495	4,273
Other softwoods	236	714	950
	28,098	29,872	57,970
Hardwoods	189	1,870	2,059
Total	28,287	31,742	60,029

Other common defects that can affect product potential to a lesser degree are lean (compression wood) and heart rot (Polyporus anceps Pk.). Leaning stems are common in southwestern ponderosa pine. It has been estimated that as much as 15 percent of the standing timber in some areas leans 5 degrees or more. Lean of 5 degrees is generally considered sufficient to develop objectionable compression wood.

Heart rot is most prevalent in old-growth timber, although it also occurs frequently in young stands. It is one of the major sources of scale deduction and product degrade.

The utilization of this low-quality timber creates technological and economic problems for a regional industry historically geared to single-product, lumber operations. Much of the saw-log material currently available is unsuited to profitable production of lumber. Lumber grade recovery from ponderosa pine in this region commonly includes as much as 40 percent grade 4 and 5 common lumber. These grades have never been more than marginal products, a situation aggravated by a depressed and declining lumber market. Since these grades of lumber make up an important part of total output, the economic impact upon industry is severe.

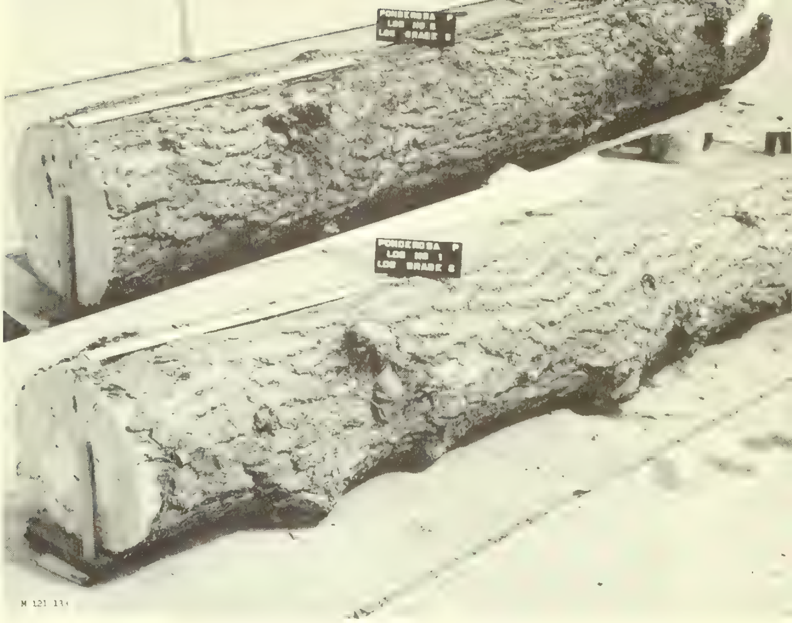

Figure 2.--Typical grade 5 (upper) and grade 6 (lower) ponderosa pine sawlogs.

Table 2.--Log grade distribution in five southwestern region timber sales

National Forest and unit	Log stand table, grade				Total
	1	2	3	4 and lower	
	Number of logs cruised				
Apache:					
Buckalou	49	94	130	723	996
Sitgreaves:					
Wiggins	5	20	81	503	609
Coconino:					
Harding Point	19	13	89	715	836
Santa Fe:					
Coyote	20	34	142	624	820
Apache:					
Black River	68	127	291	2,467	2,953
Total	161	288	733	5,032	6,214
	- - - - Percent - - - -				
Distribution	2.6	4.6	11.8	81.0	100.0

A PRELIMINARY SURVEY

In 1961, a team of Forest Service research personnel and regional industry representatives conducted a field survey and analysis of the problem. The survey verified the predominance of low-grade saw logs and lumber, and provided a basis for developing an applied research program.

Two factors were found to contribute to the overall utilization problem:

1. The quality of the timber common to the Southwest yields high proportions of the lower common grades of lumber. Much of this lumber will not return a profit.

2. Lumber, regardless of grade, is becoming a less profitable product. This is especially true for sheathing, subflooring, forming, and similar construction uses, upon which the lower common grades of lumber depend. Plywood and nonwood sheet materials have seriously encroached upon these former lumber markets.

Any program proposed to develop new products and alleviate current utilization problems must therefore concentrate upon products competitive with existing building products such as plywood, particle board, and laminated members. The program must also concentrate upon products which can either circumvent or tolerate the range of defects common to the timber involved. For southwestern ponderosa pine, the primary defect affecting product potential is the presence of numerous knots.

Housing and building construction provides the greatest potential market for wood products. Modifications are needed to create products that can compete effectively with other types of building materials. A major inherent disadvantage of wood in lumber form is the excessive labor cost of application and, therefore, high installed cost. Panel products, combined-function products, and semifinished products can all decrease installed or finished costs.

The current trend in the light-construction industry is toward component construction and coordinated component building systems. Consequently, it is desirable to consider not only individual products, but a coordinated group of new or modified products--sheathing, siding, flooring, laminated members--that would fit into a component building system. Thus an extensive product research and development program was initiated. The research program included the development, demonstration, and evaluation of new or modified products from both low-grade lumber and low-grade timber. Products from low-grade lumber included overlaid siding, laminated products, and flooring. These products can utilize extremely knotty material in standard lumber sizes, through selective cutting, masking, and preassembly methods. The program also included veneer and plywood and particle board products, each capable of utilizing low-quality timber in forms other than standard lumber.

The products considered offered greatest apparent promise for low-grade timber utilization, and required minimal changes in existing mill facilities. The products also offer potential as a combined group that could form a coordinated component building system.

TEST MATERIALS

Test materials for the study were selected by industry and research personnel at sawmills in Arizona and New Mexico, and shipped to the Forest Products Laboratory. The materials were selected from the lower or "problem" grades of logs and lumber (fig. 3). The test lumber used was all of grades 3, 4, and 5 common, and all logs for veneer were of grade 5. In addition, a grade 6 log and low-quality slabs were included as chipping material for particle board. An itemized description of all ponderosa pine test materials used is presented in appendix A, page 51.

PRODUCT DEVELOPMENT, DEMONSTRATION, AND EVALUATION

Product research included designing specific construction products peculiarly suited to the low-quality wood resource, manufacturing these products on a prototype basis, and subjecting them to standard and improvised evaluation tests. This section of the report covers the rationale behind product design, production and testing procedures, and apparent technical feasibility for each of the specific products under study.

Veneer and Plywood

Plywood manufactured for specific uses which will tolerate defects common to low-grade ponderosa pine offers considerable utilization potential. Primary consideration has

Figure 3.--A group of grade 5 and 6 ponderosa pine logs provided as test material.

been directed toward underlayment plywood. Standard sheathing and subflooring products have not received active consideration for several reasons:

1. Commercial Standard specifications for any type of plywood will be difficult to meet when only low grades of logs are utilized. The underlayment market offers promise for a specialized product that need not conform to Commercial Standards.

2. Industry has indicated interest in producing a 4- by 4-foot panel, a size preferable from the standpoint of better utilization of low-grade material. This size is not objectionable in underlayment, and may offer some advantages, but may not be well accepted as standard construction plywood.

3. Competition in the general softwood construction plywood market is formidable. If such a product could be made, entry into the market might prove extremely difficult.

Underlayment plywood is conventionally used between subflooring and finish flooring of various tiles, carpeting, or other resilient flooring to provide a smooth, relatively joint-free base (fig. 4). As such, it does not require the strength or nail-holding properties of sheathing or subflooring. If large knots can be bonded well enough to prevent delamination in use, practically any size knot could be included in underlayment panels.

U. S. Commercial Standard CS 122-60[4] requires that interior underlayment plywood be constructed with a C-repaired face veneer and C second ply, and allows remaining veneers to be of D grade. This means that the second ply (grade C) can have open defects up to 1 inch in diameter, and all remaining veneers can have open defects up to 2-1/2 inches in diameter. A specialized underlayment plywood with no appreciable open defects in the upper three or four plies may therefore offer a distinct improvement over standard underlayment.

The product developed does not conform to Commercial Standard veneer grade specifications. In the test plywood, sound knots of any size were allowed in all veneers. Open defects were not allowed in any except the back, however, so the product had four sound plies.

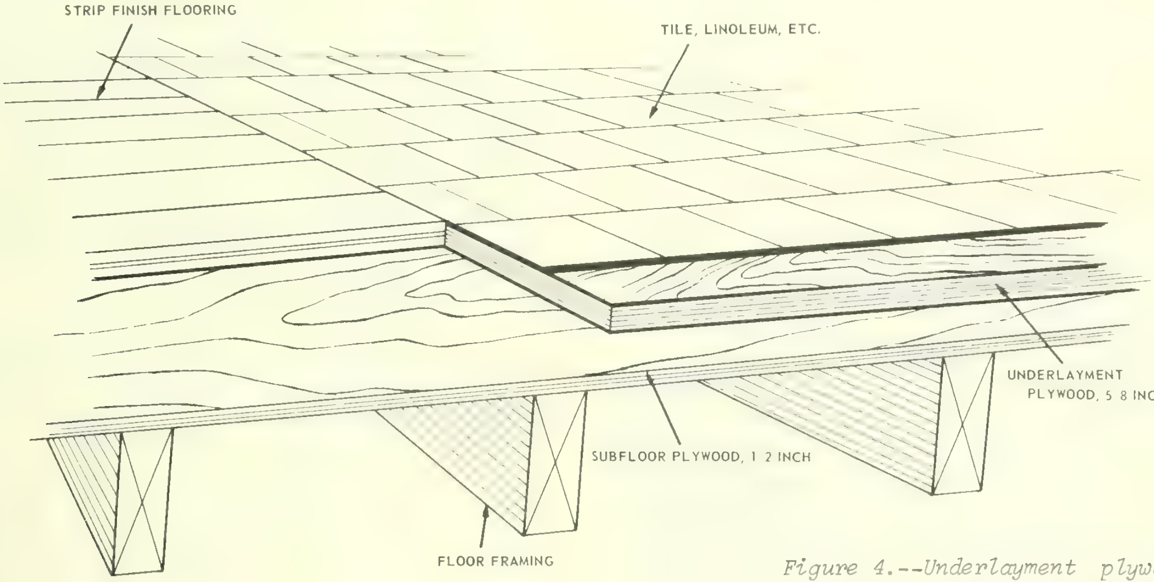

Figure 4.--Underlayment plywood acts as a filler between subflooring and finished flooring.

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[4] *U. S. Department of Commerce. U. S. commercial standard CS 122-60 for western softwood plywood. Ed. 4, 22 pp., illus. Effective Dec. 31, 1960; revised April 15, 1963.*

Veneer production

Two thicknesses of veneer were desired: one suitable for five-ply touch-sanded underlayment panels 5/8 inch thick, and one suitable for lumber-core laminated flooring panels. For the underlayment plywood, drying shrinkage, hot-press compression, and touch sanding were estimated to require a combined allowance of 0.090 inch. This allowance, plus desired finished panel thickness of 0.625 inch, required a green veneer thickness of 1/7 inch (0.143).

The lumber-core laminated flooring panels, discussed at length later in the report, were designed to require back and face veneers approximately 1/4 inch thick (0.235 inch minimum for a panel thickness of 1-1/4 inches). It was anticipated that the thicker veneer would cut less smoothly, and would require greater sanding allowance to provide a suitable finished surface. A minimum allowance of 0.050 inch in veneer thickness was estimated for drying shrinkage, cold-press compression, and sanding. Accordingly, all veneer cut for use in lumber-core panels was cut 3/10 inch thick (0.250 + 0.050).

Four grade 5 saw logs were provided for conversion into veneer (see fig. 3). Eight 52-inch test bolts were cut from the four 10-foot logs, one bolt from each log designated for 1/7-inch veneer, the other for 3/10-inch veneer. The test bolts are described in appendix A, table 18.

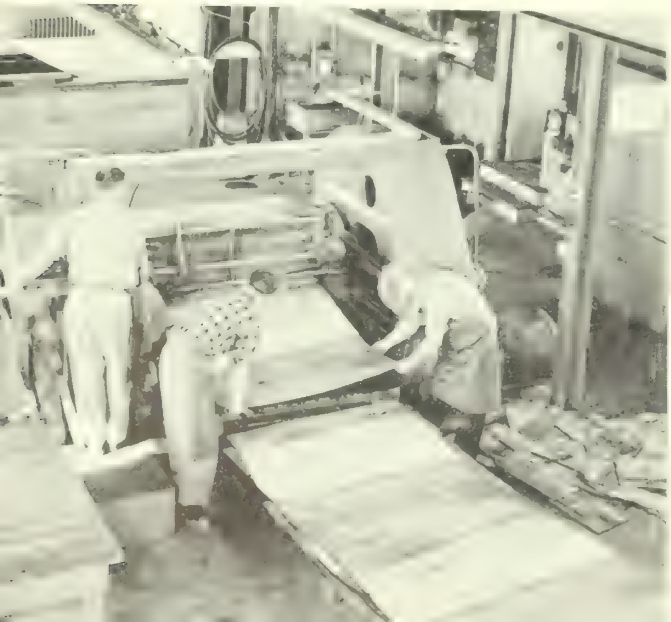

Figure 5.--Veneer is cut from a 4-foot peeler bolt on a rotary veneer lathe.

The four bolts designated for 1/7-inch veneer were heated under water at 140° F. for 60 hours or more. The bolts designated for 3/10-inch veneer were heated for a similar period of time at 160° F. Prior veneering tests had indicated that the higher temperature was desirable for cutting thick veneer, although it may induce end splitting in the bolts. All bolts heated at 160° F. developed heartwood splits during heating; the splits were confined to the core portion of the bolts, however, and did not affect recovery.

The heated test bolts were debarked, inspected again for noticeable defect, and converted to veneer on a 4-foot rotary veneer lathe (fig. 5).

Lathe knife and pressure bar settings used in cutting the veneer (fig. 6) are shown in table 3.

Some preliminary veneer runs were made with horizontal pressure bar openings of 0.128 for 1/7-inch veneer and 0.285 for 3/10-inch veneer. These settings appeared to exert more pressure against the bolt than necessary. Less shelling was experienced by allowing 0.005 inch greater horizontal clearance (0.133 and 0.290, respectively).

All veneer cut smoothly with the exception of bolts 3-1 and 3-2, which contained wide bands of compression wood. The compression wood caused a comparatively rough cut, and caused some shelling in the 3/10-inch veneer, but did not result in the loss of any veneer.

All test bolts except one were cut without difficulty with 6-inch chucks through the entire cutting process. Bolt 5-2, the largest bolt from which 3/10-inch veneer was cut, required 8-inch chucks.

The green veneer was clipped to remove roundup, wane, and other inadmissible defects, and was clipped to rough panel widths where possible. The green veneer was measured for total green recovery, but was not graded. The veneer was dried in a conventional steam-heated continuous roller dryer. The average time and temperature required to adequately dry heartwood and sapwood veneer of both thicknesses is indicated in table 4.

Table 3. --Veneer lathe adjustment

Bolt number	Desired veneer thickness		Knife angle	Pressure bar		
	Green	Finished		Bevel	Vertical opening	Horizontal opening
	Inches	Inches	Degrees-minutes		Inches	Inches
2-2, 3-1, 4-1, 5-1	0.143	0.125	89°50'	15°	0.028	0.133
2-1, 3-2, 4-2, 5-2	.300	.250	89°40'	15°	.030	.290

The 1/7-inch veneer was dried without difficulty (fig. 7). Sheets containing bands of compression wood buckled only slightly. All intergrown knots remained intact in the dry veneer, while most encased knots fell out during drying. Since there were relatively few encased knots, a high recovery of solid veneer was obtained.

The first run of 3/10-inch veneer was dried in a single pass through the dryer. Much of the veneer developed severe end splits, which progressed into the sheet as much as 12 inches. It was believed that the splitting could have resulted from the rather long period of continuous exposure to high temperature and excessively rapid drying from the ends of the thick veneer.

In an attempt to prevent or minimize end splitting, the second run of 3/10-inch veneer was dried in two or more passes through the dryer (table 4). In addition, 1-1/2 inch kraft-type tape was applied to both ends of each

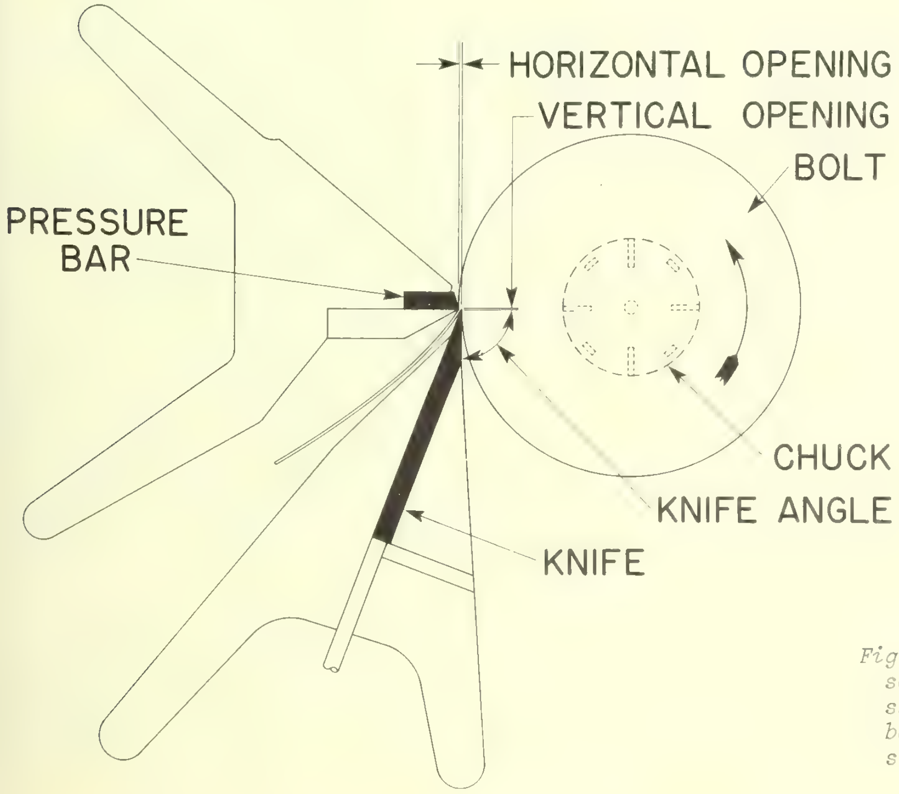

Figure 6.--Diagrammatic cross section of a veneer lathe, showing position of pressure bar and knife, and associated settings.

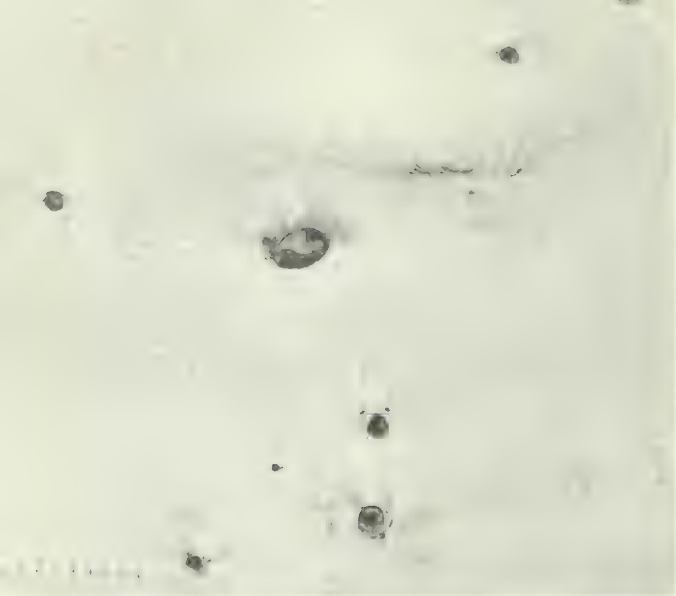

Figure 7.--Dry 1/7-inch veneer had relatively few open defects.

full-size sheet, on the tight side of the veneer. The tape performed dual functions of retarding end drying and mechanically restraining the veneer from splitting. The veneer so treated was successfully dried without appreciable end splitting (fig. 8). The combination of taping and multiple-pass drying was apparently effective in preventing splitting, although the relative effectiveness of the two treatments is not known.

Table 4. --Veneer drying time

Type of veneer and thickness	Temperature	Drying time	Final moisture content
	Degrees, F.	Min.	Percent
1/7-inch:			
Sapwood	310	18-19	2- 8
Heart and sap	310	18-19	2- 6
Heartwood	310	9	1- 2
3/10-inch, single pass:			
Sapwood	310	46	4-10
Heart and sap	310	46	3- 7
Heartwood	310	27	2- 6
3/10-inch, multiple pass:			
Sapwood--			
First pass	310	20.5	--
Second pass	310	20.5	4-30
Third pass	310	3	4-10 (final)
Heart[1] and sap--			
First pass	310	20.5	--
Second pass	310	20.5	3- 9 (final)

[1] All heartwood contained some inner sapwood, and thus required an intermediate drying time.

All dried veneer was remeasured and graded twice, by the two following grading systems:

1. Commercial Standard grades:
    - (A) Essentially clear.
    - (B) Clear, with rough grain.
    - (C) Knots, 1-1/2 inches; knotholes, 1 inch maximum.
    - (D) Any knot; knotholes, 2-1/2 inches maximum.
2. Improvised grades, suited to the segregation of sound knots from open defect:
    - (a) Clear material.
    - (b) Sound knots up to 1-1/2 inches in diameter.
    - (c) Sound knots over 1-1/2 inches in diameter.
    - (d) Open defect, patchable with conventional veneer patches.
    - (e) Open defect, nonpatchable.

The minimum width considered in grading by either system was 6 inches.

Tables 5 and 6 show total veneer recovery, manufacturing losses, and dry veneer by grade for each grading system.

The Scribner Decimal C log rule is commonly employed to measure saw-log volume in the Southwest. It is, therefore, of some interest to compare product recovery with the Scribner Decimal C scale of the logs and bolts used in the study. Table 7 presents log and bolt scale, and dry veneer recovery after final grading and inspection. Veneer recovery is shown in square feet, in board-foot units of 144 cubic inches, and in terms of equivalent 3/8-inch plywood.

In computing a plywood-recovery factor based on Scribner log scale, it should be noted that the trim loss shown in column three would not ordinarily be incurred in commercial operation. This trim loss was

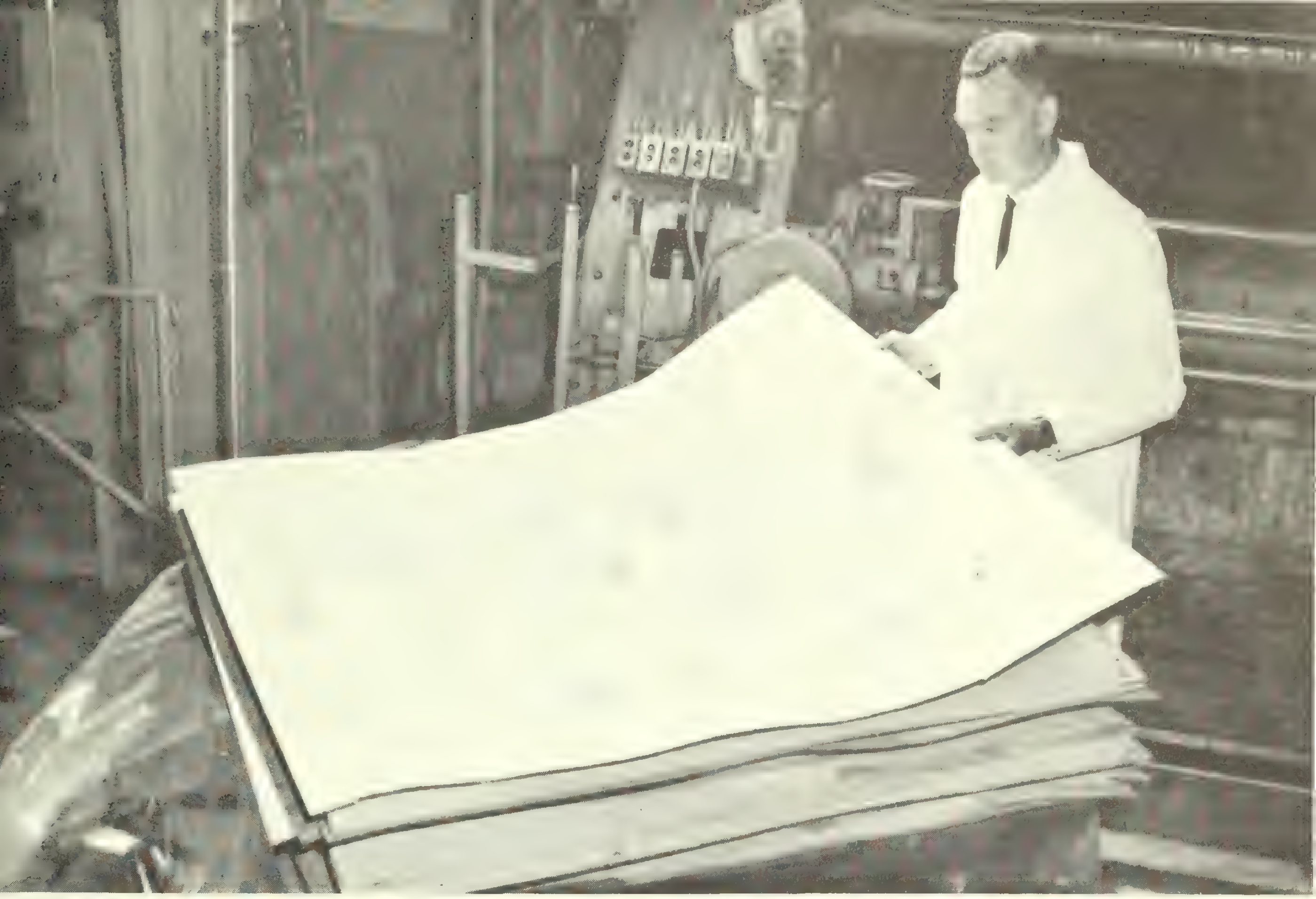

Figure 8.--The heavy 3/10-inch veneer dried without appreciable end-splitting, and practically all knots remained intact in the dry veneer.

Table 5. --Veneer manufacturing losses and total recovery

Bolt number	Veneer thickness		Veneer loss		Green veneer recovery	Drying loss	Dry veneer recovery
	Green	Average dry	Round-up	Green clip			
	Inches		Lineal inches				
2-2	1/7	0.138	[1] 332	90	1,488	80	1,408
3-1	1/7	.138	162	8	688	50	638
4-1	1/7	.138	196	44	1,222	103	1,119
5-1	1/7	.138	182	[2] 207	2,066	164	1,902
Total			872	349	5,464	397	5,067
2-1	3/10	.292	180	60	833	33	800
3-2	3/10	.292	85	9	303	17	286
4-2	3/10	.292	97	8	617	37	580
5-2	3/10	.292	[3] 216	17	729	34	695
Total			578	94	2,482	121	2,361

Includes loss of 78 inches due to chuck change.

[2] High green clip loss due primarily to intergrown bark pocket and mismanufacture (chip gouge).

[3] High round-up loss due primarily to chuck slipping, and subsequent change to larger chuck.

Table 6. --Veneer grade recovery

Bolt number	Green veneer thickness	Grade recovery					Cull	Dry recovery, cull excluded
	Inches	Lineal inches					Lineal inches	
		COMMERCIAL STANDARD GRADES						
		A	B	C	D			
2-2	1/7	0	24	297	1,087		0	1,408
3-1	1/7	110	0	303	200		25	613
4-1	1/7	31	0	273	799		16	1,103
5-1	1/7	571	0	255	1,073		3	1,899
Total		712	24	1,128	3,159		44	5,023
2-1	3/10	0	0	0	800		0	800
3-2	3/10	0	0	89	194		3	283
4-2	3/10	13	0	0	500		67	513
5-2	3/10	390	0	20	282		3	692
Total		403	0	109	1,776		73	2,288
		IMPROVISED GRADES						
		a	b	c	d	e		
2-2	1/7	0	311	1,056	41	0	0	1,408
3-1	1/7	111	304	168	34	0	21	617
4-1	1/7	37	254	290	509	11	18	1,101
5-1	1/7	562	228	855	201	53	3	1,899
Total		710	1,097	2,369	785	64	42	5,025
2-1	3/10	0	0	653	110	37	0	800
3-2	3/10	0	63	184	36	0	3	283
4-2	3/10	13	0	323	132	86	26	554
5-2	3/10	404	6	274	8	0	3	692
Total		417	69	1,434	286	123	32	2,329

due to the length of the test logs, and should be deducted from log scale before computing recovery factors. A valid overall recovery factor for the group of test logs can be computed as

$$\frac{\text{3/8-inch plywood recovery}}{\text{log volume, minus trim loss}},$$

$$\text{or } \frac{1156}{540-67} = 244$$

The recovery factor of 2.44 square feet of 3/8-inch plywood per board foot of log volume, Scribner Decimal C scale, compares favorably with recoveries commonly experienced in commercial softwood plywood production.

As is evident in the grade recovery shown in table 6, a relatively large proportion of the 1/7-inch veneer recovered had no appreciable open defect. A product, such as underlayment,

Table 7. --Study log and bolt volume, and associated veneer recovery

Log No.	Volume, Scribner, Decimal C	Trim loss[1]	Bolt No.	Volume, Scribner, Decimal C	Dry veneer recovery			Equivalent[3] 3/8-inch plywood
					Thickness	Quantity	Volume[2]	
	Bd. ft.	Bd. ft.		Bd. ft.	Inches	Sq. ft.	Bd. ft.	Sq. ft.
2	170	21	2-1	78	0.292	289	84.3	193
			2-2	71	.138	508	70.0	169
3	60	7	3-1	27	.138	221	30.5	74
			3-2	26	.292	102	29.8	68
4	120	15	4-1	53	.138	398	54.9	133
			4-2	52	.292	185	54.1	123
5	190	24	5-1	84	.138	686	94.5	229
			5-2	82	.292	250	72.9	167
Total	540	67	--	473	--	--	491.0	1,156

[1] Loss shown was incurred in cutting 10-foot test logs into 52-inch bolts.

[2] Actual dry recovery, in board-foot units of 144 cubic inches.

[3] Based upon nominal veneer thicknesses of 1/8 inch and 1/4 inch.

which requires a high proportion of sound, but not necessarily clear veneer, can therefore capitalize upon this inherent quality. In view of the high recovery of sound veneer, it was considered feasible and practical to limit open defect in the final product to the fifth or back ply only. The resulting panel is of considerably higher quality, with respect to open defect, than is normally produced under Commercial Standard specifications.

Panel layup and manufacture

Preliminary gluing trials were conducted to determine which adhesive systems would be suitable for underlayment panel construction, and the extent to which knots might interfere with the process. Twenty-four small three-ply test panels were fabricated from 1/8-inch veneer. Three adhesives--a hot-press blood-soybean blend, a cold-press soybean, and a hot-press exterior-type phenolic adhesive--were compared. The soybean and blood-soybean blend glues are interior-type glues. Other variables investigated included the effect of heartwood and sapwood, and the size and location of knots in the different plies.

Test specimens were subjected to standard shear and delamination tests. All test panels passed cyclic delamination test requirements for interior softwood plywood.[5] Average strengths and wood failures for dry shear specimens cut from the panels are shown below:

Adhesive	Dry shear strength (P.s.i.)	Wood failure (Percent)
Phenolic	220	90
Blood-soybean	211	48
Soybean	204	62

Some difficulty was experienced initially in obtaining uniform glue spreads over knotty areas. When care was taken in spreading glue, however, knots and knotty material posed no particular problems.

Blood-soybean adhesive proved superior in some respects (notably wet shear strength) to the soybean interior adhesive used. It was, therefore, adopted for use in producing demonstration underlayment panels.

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[5] *For cyclic delamination test specifications, see footnote 4, p. 5.*

The 1/7-inch veneer was sorted into face, core, crossband, and back material. All veneer with appreciable open defect was placed in crossband and back stock. All veneer was clipped to 50-inch lengths, and full sheets were clipped to 50-inch widths. Fourteen 50- by 50-inch five-ply panels were laid up from the veneer, which fully utilized all 1/7-inch veneer. Open defect in face veneer was limited to splits or knot checks no more than 1/16 inch in width. Open defect in crossband and core material was limited to splits and checks not exceeding 1/16 inch in width, and circular open defects not exceeding 1/4 inch in diameter. Material with larger open defects was either clipped to provide sound crossbanding, or was utilized as back veneer. Two panel faces were patched with conventional boat patches, primarily to demonstrate the possibility of patching.

No difficulty was encountered in laying up panels with four essentially sound plies. The requirement for sound veneer thus imposed did not hinder complete utilization of the veneer available. A total of 498 linear inches of veneer, or approximately 13 percent of dry footage, was lost at the clipper in laying up the 14 panels. Of this, one-third was lost in sizing full sheets and two-thirds was lost in clipping open defect from crossband material.

The veneer loss sustained in laying up the panels is subject to some qualification. Very little defect was clipped from the green veneer. Defect that appeared to offer any chance for utilization was allowed to remain in the veneer through the drying process. Consequently, some of the clipping loss incurred in panel layup would probably have been clipped from the green veneer in a commercial operation. Also, much of the lost veneer could have economically been patched with efficient commercial patching equipment.

The plywood panels were fabricated with blood-soybean adhesive at a spread of 44 pounds per M square feet of single glue line. All adhesive was applied by double spreading crossband veneer in a double-roll spreader. The panels were hot pressed at a press temperature of 240° F., a pressure of 150 pounds per square inch, and a cycle time of 15 minutes (fig. 9). The panels were hot stacked upon removal from the press (fig. 10).

Thermocouples were placed in the interior glue lines of the first two panels pressed to determine interior glue-line temperatures. The temperature reached 200° F. in 5 minutes, and attained a maximum of 230° F. during the 15-minute pressing cycle. This is considered an adequate exposure to heat for complete curing of all glue lines.

Five-ply test specimens from three panels were subjected to soak-dry delamination tests and shear tests. In addition, one panel was sectioned into 6-inch squares to evaluate glue-line integrity and panel quality. All specimens performed satisfactorily and exceeded Commercial Standard requirements for interior plywood. Again, knots glued without difficulty, exhibited good glue-line integrity, and posed no problems.

The completed plywood panels were trimmed to 48-inch squares. The panels averaged 0.655 inch thick, which left an average sanding allowance of 0.030 inch to bring the material to standard 5/8-inch thickness.

Three panels were trimmed to 42 inches in width, to facilitate test sanding on a two-drum oscillating sander. First and second sander drums carried 1/2-60 grit closed coat garnet and 2/0-100 grit closed coat garnet, respectively. The high pitch content of the ponderosa pine panels caused rapid plugging of the closed coat paper; otherwise, no difficulty was encountered in sanding the panels to 5/8-inch thickness. The resulting touch-sanded surface was fully satisfactory for the intended use. Excessive paper plugging could be avoided by using open coat papers and wide belt sanders.

It appears that the green veneer thickness of 1/7 inch (0.143 inch) is correct for the 5/8-inch underlayment. The resulting panel thickness allowance is just sufficient to provide for drying shrinkage, hot-press compression, and adequate sanding.

Plywood evaluation

The test sample of eight veneer bolts is an insufficient basis for obtaining reliable veneer recovery information. The study logs selected, however, represented the range of sound de-

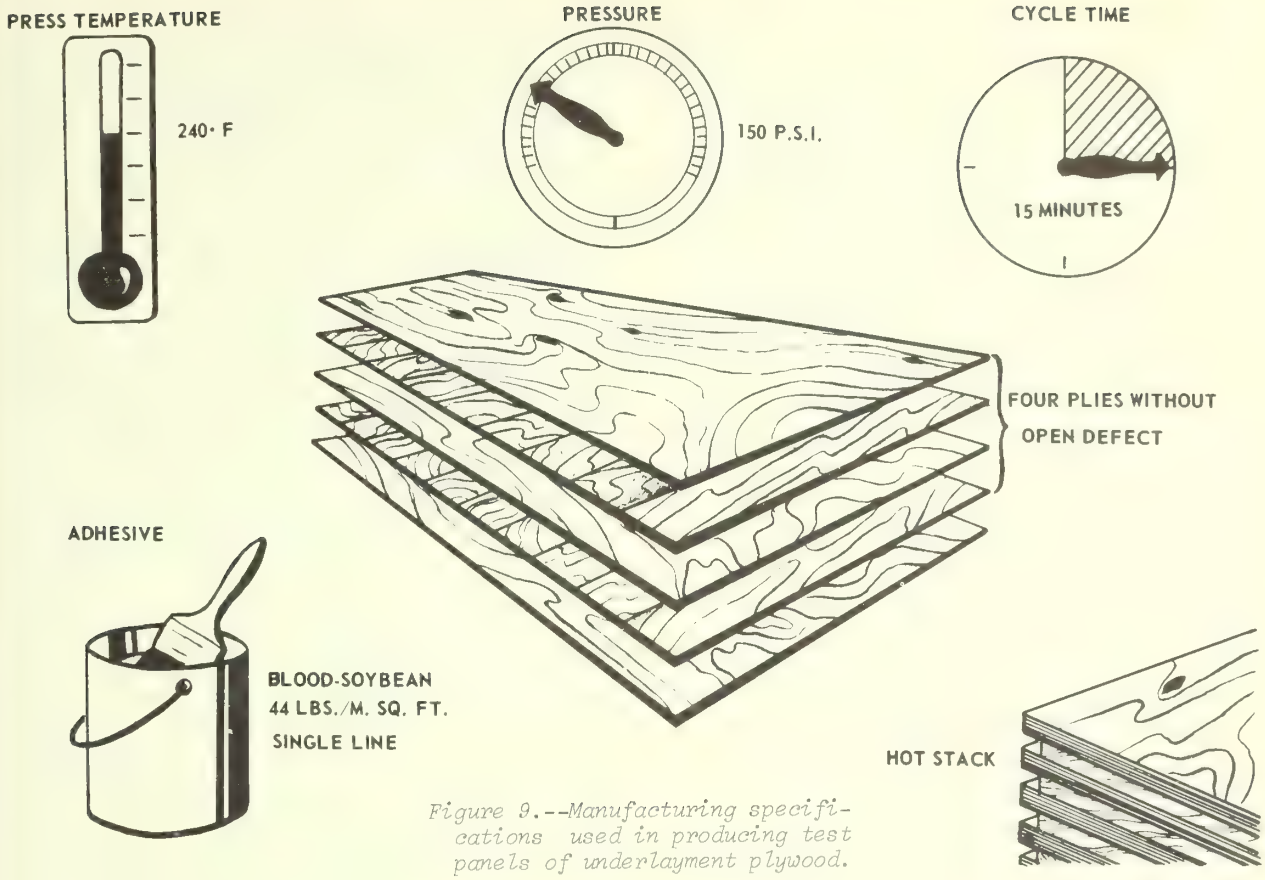
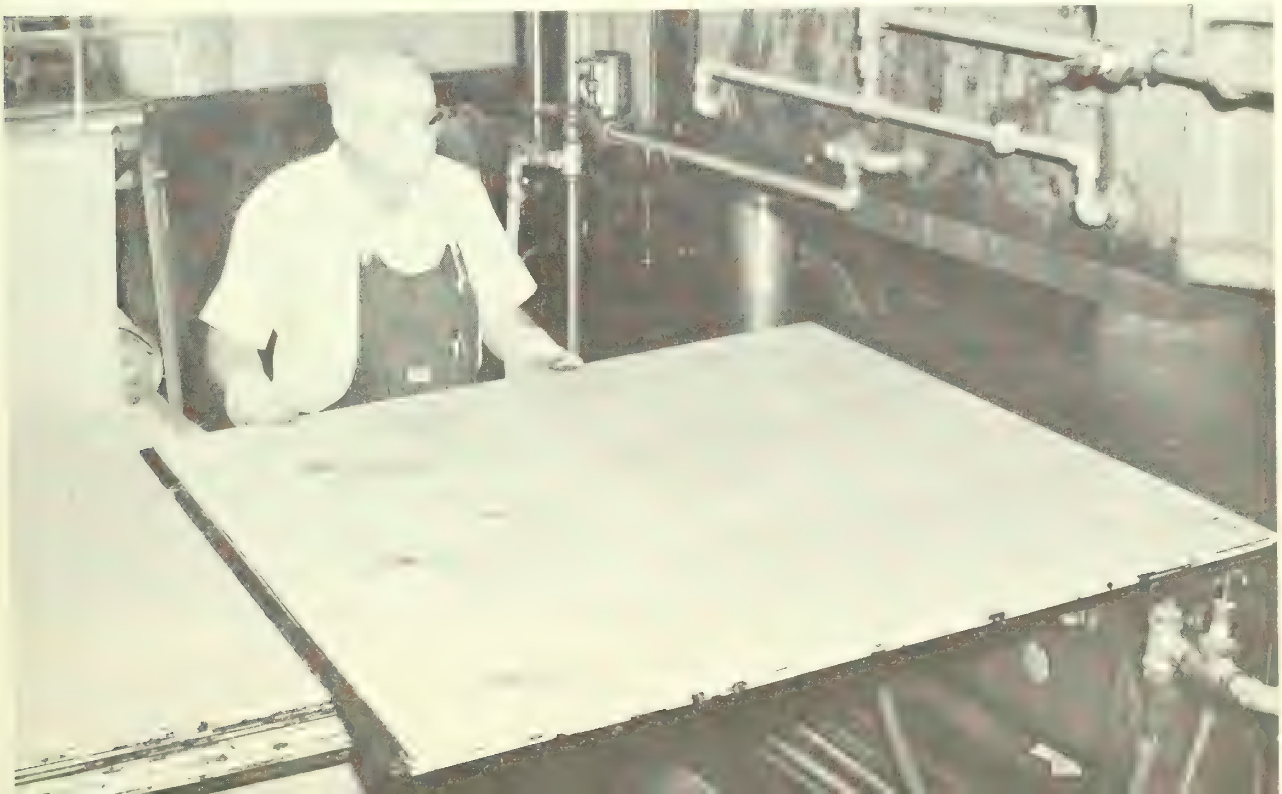


Figure 9.--Manufacturing specifications used in producing test panels of underlayment plywood.

Figure 10.--A 4-foot test panel of five-ply, 5/8-inch ponderosa pine underlayment plywood is removed from the press and hot stacked.



fect commonly encountered in grade 5 saw logs. Two of the study logs were more nearly representative of the low side of the grade. Consequently, the veneer grade and quantity recovery experienced in this study is probably below that which could be obtained commercially from a mixture of peeler logs including some logs of higher grade.

Although all test bolts contained numerous knots, more than 80 percent of the 1/7-inch veneer recovered was sound (see table 6). A product requiring a high proportion of sound, but not necessarily clear, material appears to offer the best utilization opportunity. The proposed underlayment plywood can capitalize upon the high proportion of sound veneer. In addition, since underlayment is a nonstructural application, stiffness and strength deficiencies will not limit its use. Compensating additional thickness and shorter span requirements common to load-bearing structural uses will be avoided. No strength or stiffness tests were made on these panels.

Primary consideration has been given to utilizing 4-foot peeler material and constructing 4- by 4-foot panels. The 4-foot or 52-inch veneer bolt offers substantial advantages in maximizing recovery from smaller, low-quality, rapidly tapering timber. The common practice of logging saw logs in multiples of 4 feet also coincides well with 4-foot bolt utilization. The equipment required to handle and process 4-foot veneer and panels is smaller and entails less capital investment. Product recovery, however, remains the major important advantage. In the smaller, low-grade timber under consideration, utilizing standard 8-foot veneer bolts could be expected substantially to lower net-product recovery.

In considering 4- by 4-foot panel production, an underlayment product again appears to have advantages. Longitudinal expansion and contraction in underlayment panels tend to "open" the joints between panels, and occasionally cause the joint to show through tile or linoleum. The joints between 4-foot panels will open less, due to the shorter panel length.

Strength and stiffness tests on laminated lumber-core flooring, discussed in detail in a later section of the report provide some idea of the strength characteristics of knotty veneer. They indicate that numerous large knots in the veneer materially lower the strength and stiffness of the final product, primarily because of the large areas of short grain associated with the knots.

Average stiffness of the veneer used in the flooring was only 70 percent of that expected for the species, and modules of rupture was approximately one-third of the average for the species. Brash tension failures in the areas of steep grain further indicate that impact strength would be low. The results of the tests lead to the conclusion that plywood constructed from knotty ponderosa pine veneers may not perform well in load-bearing structural uses, unless thickness or span compensations are made.

Commercial Standard CS 259-63,[6] which sets forth the commercial specifications for southern pine plywood, limits sound knot size in grade D panel backs to 2-1/2 inches in diameter. This limitation has been prescribed because of the known effect of knots and surrounding short grain upon load-bearing qualities. A similar limitation applied to ponderosa pine veneer used in structural grades of plywood might insure satisfactory strength and stiffness properties.

If a better "grade mix" of logs were used in manufacturing ponderosa pine plywood, sheathing grade specifications could undoubtedly be met. The plywood should then be fully adequate for structural diaphragm uses such as wall sheathing and soffits. Commercial Standard CS 122-60 groups the western softwoods, other than Douglas-fir, into three groups according to their relative stiffness. Ponderosa pine is included in group 3, the lowest. It is subject, therefore, to the limitations in structural use imposed upon group 3 softwoods.

FHA minimum property standards[7] allow the use of groups 2 and 3 softwood plywoods that meet Commercial Standard specifications as underlayment (nonstructural), subflooring, wall sheathing, and roof sheathing. When used as roof sheathing or subflooring, however, compensating additional panel thickness or shorter support spans must be used. Compensating thickness or span dimensions are not required for underlayment and wall sheathing uses, since they are nonload bearing in nature.

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[6] *U. S. Department of Commerce. Commercial standard CS 259-63, southern pine plywood. 1963.*

[7] *U. S. Federal Housing Administration. Minimum property standards for one and two living units. Fed. Housing Admin. Pub. 300, Rev. 4. May 1963.*

Use standards, however, are based upon average characteristics of the species. As previously mentioned, load-bearing strength of veneers from low-grade ponderosa pine appears to be far below average for the species. Consequently, practical uses of sheathing-grade plywood made from veneers containing many large knots are probably limited to nonload-bearing applications. The range of potential use for sheathing-grade ponderosa pine plywood will depend heavily upon the quality of timber being utilized. This factor should receive careful consideration when production of a sheathing-grade product is considered.

Particle Board

Particle-board manufacture may offer a means of utilizing logs that are too small or too rough to be of value in the manufacture of boards or veneer. In addition, much sawn material currently considered mill waste is suitable for the production of particle board. Exploratory tests at the Forest Products Laboratory have shown that ponderosa pine is well suited to particle-board manufacture. Specific products that should warrant consideration include flake-type furniture-core particle board, a furniture core or underlayment board made from standard planer shavings, and a newly developed thick board made from pulp-type chips in combination with standard flakes.

Appropriate raw material was obtained to evaluate the feasibility of producing these particle-board products from low-grade ponderosa pine. Raw materials included one 12-foot grade 6 saw log, 500 pounds of debarked sawmill slabs, and 300 pounds of planer shavings (appendix A). The planer shavings were taken from the lower head of a 21-inch, Model 484M Woods planer.[8]

Two general types of particle board were manufactured. The first of these was conventional flat-press furniture-core particle board in six variations. The second type was the thick, three-layer chip and flake board designed for partitioning, with possible modification for decking use.

Flake and shaving board production

Furniture-core particle boards made of conventional flakes, of planer shavings, and of a combination of the two were included in the tests. Six types or variations of particle board were selected for manufacture, including:

1. Shavings board: This board was made to Forest Products Laboratory standard specifications,[9] with planer shavings from a typical commercial high-speed planer.

2. Flake-shaving board: This board was made to standard specifications from flakes nominally 1 inch long, 0.015 inch thick, and random width, and planer shavings mixed at a weight ratio of one to one.

3. Three-layer flake board: This board contained a core made from conventional flakes nominally 1 inch long, 0.025 inch thick, and random width. Each face layer, comprising one-eighth of the total weight of wood material, was made of flakes 1 inch long, 0.005 to 0.010 inch thick, and random width.

4. Three-layer flake-shaving board: This board contained a core made of conventional flakes 1 inch long, 0.025 to 0.030 inch thick, and random width. Each face layer, comprising one-eighth of the total weight of wood material, was made of fines produced by hammer-milling planer shavings.

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[8] *Mention of trade names and commercial enterprises or products is solely for necessary information. No endorsement by the U. S. Department of Agriculture is implied.*

[9] *Specifications designated as standard by the Forest Products Laboratory are described on page 16.*

5. Forest Products Laboratory standard particle board: This board was made entirely from conventional ponderosa pine flakes nominally 1 inch long, 0.015 inch thick, and random width.

6-7. Two-layer flake board: This board was made from conventional ponderosa pine flakes 1 inch long, 0.015 inch thick, and random width, with a top layer of fine material. The fine material, comprising one-eighth of the total weight of wood material, was produced by hammer-milling flakes. Two series of these boards were made, one with phenolic binder, the other with urea binder.

The conventional flakes used in manufacturing the particle boards were prepared from the sawmill slabs provided, and from other scrap material. The material was cut into blocks 3 inches long in the grain direction to facilitate flaking on the laboratory flaker. The blocks were vacuum soaked in an autoclave to raise the moisture content to a point approximating green wood. When removed from the autoclave, the material had an average moisture content of 107 percent.

Sufficient flakes of the specified dimensions for each type of particle board were cut with a small laboratory flaker. The material was fed into the flaker with direction of grain parallel to the plane of rotation of the disc-type cutter head. The knives on the cutter head were adjusted to control thickness of flake, and spur cutters similarly controlled length of flake in the grain direction. All wet material flaked without difficulty. Flaking attempted with some air-dry blocks at 12 percent moisture content was unsuccessful. The dry material flaked irregularly and produced badly curled flakes. Some difficulty was also experienced in cutting 0.005-inch-thick flakes from either wet or dry blocks. Again wet blocks exhibited superior flaking properties.

The flakes were allowed to air dry to approximately 15 percent moisture content, then were hammer-milled just sufficiently to break them into random widths. Smaller particles were removed by screening the hammer-milled flakes through a 16-mesh screen. A quantity of flakes and a similar quantity of planer shavings were hammer-milled in a 1/16-inch hammer-mill screen to produce fine material for the faces of multi-ply boards. All material was dried to approximately 6 percent moisture content before use.

A sample of each group of flakes was measured to determine the range of flake thickness. Table 8 indicates the total thickness range encountered, and the thickness range encompassing 90 percent or more of the flakes, for each nominal flake thickness.

Table 8. --Range of flake thickness in a sample of ponderosa pine flakes, measured at 6 percent moisture content

Nominal thickness (Inches)	Thickness range		
	Minimum	Maximum	Including 90% of flakes
	- - - - Inches - - - -		
0.005-0.010	0.004	0.012	0.005-0.009
.015	.010	.019	.012- .017
.025- .030	.020	.038	.025- .034

Three boards of each of the six types of conventional particle board under consideration were manufactured. Liquid urea-formaldehyde adhesive was applied to the particles by spraying. The boards were felted by hand, following the specifications previously discussed for each type of board. All boards were formed and pressed to the following Forest Products Laboratory standard specifications:

1. Gross size: 1/2 inch by 24 inches by 28 inches.
2. Density: 35 pounds per cubic foot.
3. Moisture content of particles before spraying: 6 percent.
4. Resin: Liquid urea formaldehyde, uncatalyzed. In addition, three boards of the two-layer flake board type were made with a phenolic-resin adhesive.
5. Resin content: 8 percent.
6. Moisture content of particles before pressing: 12 percent.
7. Temperature of press: 325^{0} F.
8. Pressure: Press to 1/2-inch stops in 3 to 4 minutes.
9. Time in press: 15 minutes.

The boards were cut into test specimens to be subjected to standard strength and dimensional stability tests. The strength tests included internal bond and static bending strength determinations. Dimensional stability tests included subjecting specimens of each type of board to the following conditions:

1. Vacuum-pressure soak.
2. Soak.
3. Ovendrying.
4. 80° F., 30 percent relative humidity.
5. 80° F., 65 percent relative humidity.
6. 80° F., 80 percent relative humidity.
7. 80° F., 90 percent relative humidity.

Three-layer-thick particle board production

The second type of particle board considered was a board 1-3/4 inches thick with a core of conventional 5/8-inch pulp chips and face layers of conventional 0.015-inch by 1-inch, random width, flakes. This type of board, although in the early experimental stage at present, offers considerable promise as a partitioning and, with modification, decking material. Coarse chips for such a board can be produced from extremely low-grade, rough material, including low-grade logs and debarked slabs.

The grade 6 ponderosa pine saw log provided as test material was canted and chipped into conventional 5/8-inch pulp chips to provide core material. Face material consisted of the standard 1-inch by 0.015-inch flakes of random width previously described. The flakes used in each face comprised one-eighth of the total weight of wood material in the board.

Six test boards 24 by 28 inches were manufactured, three with a phenolic resin binder and three with a urea-formaldehyde binder. The liquid adhesive was applied to the particles by spraying. The boards were felted by hand and all boards were formed and pressed to the following specifications:

1. Gross size: 1-3/4 inches by 24 inches by 28 inches.
2. Density: 22 pounds per cubic foot.
3. Moisture content of particles before spraying: 6 percent.
4. Resin: Liquid urea formaldehyde, uncatalyzed. Phenolic resin.
5. Resin content: Core, 4 percent.
   Faces, 8 percent.
6. Moisture content of particles before pressing: 12 percent.
7. Temperature of press: 325° F.
8. Pressure: 150 pounds per square inch maintained until the desired board thickness of 1-3/4 inches was attained, then adjusted to maintain thickness. Thickness is attained without press stops by using a dial indicator attached to a press platen.
9. Time in press: 55 minutes.

The boards were cut into test specimens to be subjected to the same strength and dimensional stability tests previously outlined for conventional boards.

In addition to the six test boards produced, sufficient material was on hand to manufacture seven boards 2 feet by 8 feet according to the same specifications used for the urea-bonded test boards (figs. 11, 12). The large boards were trimmed, the faces were sanded lightly, and a groove 1/2 inch square was routed down the center line of the edges of the boards. The groove provided for splining the boards together in a partition structure with strip molding machined in the form of a cross (fig. 13).

The press cycle time of 55 minutes used in the manufacture of this product need not necessarily be a deterrent to commercial production. Representatives of electronic equipment firms state that this type of product can be manufactured with extremely short cycle time through the use of radio-frequency heating. The most efficient pressing operation would probably combine steam-heated platens and radio-frequency heating. Conventional steam-heated presses can be converted to this type of unit through the addition of electronic insulation and radio-frequency energized platens. It has been estimated that a 15-kilowatt radio-frequency unit would be sufficient to reduce press cycle time to approximately 2 minutes for particle board 1-3/4 inches thick. The product would also lend itself well to manufacture in a Chapman-type progressive press.

Figure 11.--The 1-3/4-inch, 2-foot by 8-foot particle boards were felted by hand through a screen to achieve particle distribution.

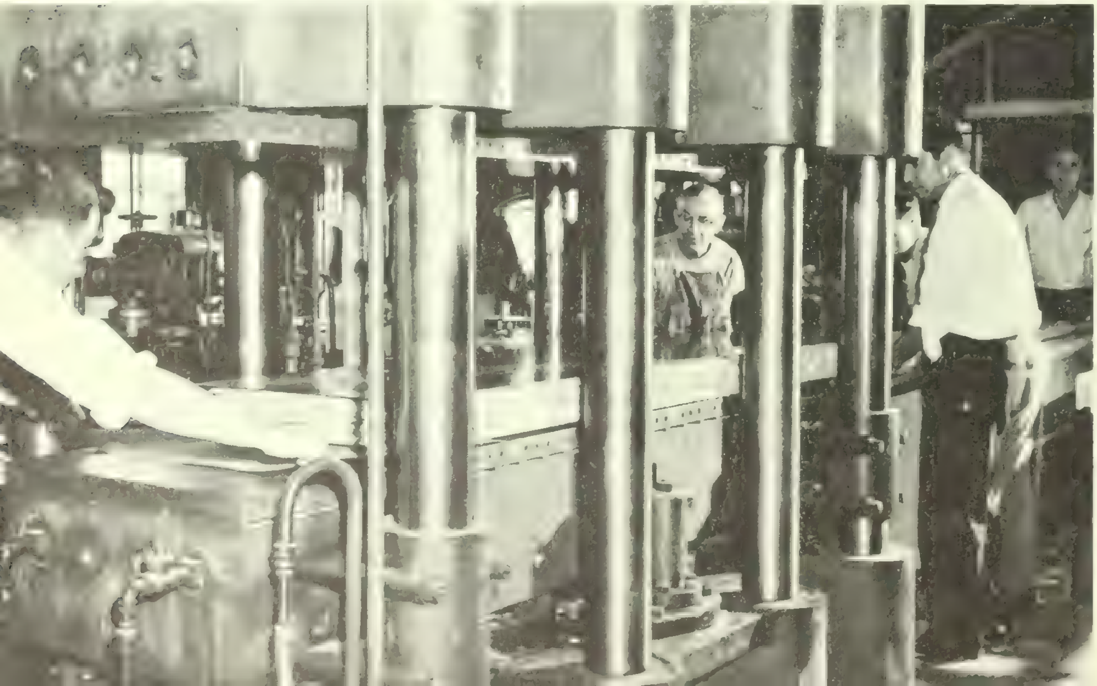
Particle board strength tests

The ponderosa pine particle boards were tested for strength in static bending and internal bond. Five specimens for each test were taken from each board. The average strength values observed in the tests are given in table 9.

For comparative purposes, Commercial Standard CS 236-61[10] sets the following minimum allowable limits for mat-formed particle board:

Property	Individual minimum	Average of 10, minimum
	(lbs./sq. in.)	
Modulus of rupture	1,450	1,600
Modulus of elasticity	200,000	250,000
Internal bond	50	60

Figure 12.--The mats for these hand-felted boards were then hot-pressed at 325°F. to the desired thickness.



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[10] U. S. Department of Commerce. U. S. commercial standard CS 236-61 for mat-formed particle board (interior use). 9 pp., illus. June 1961.

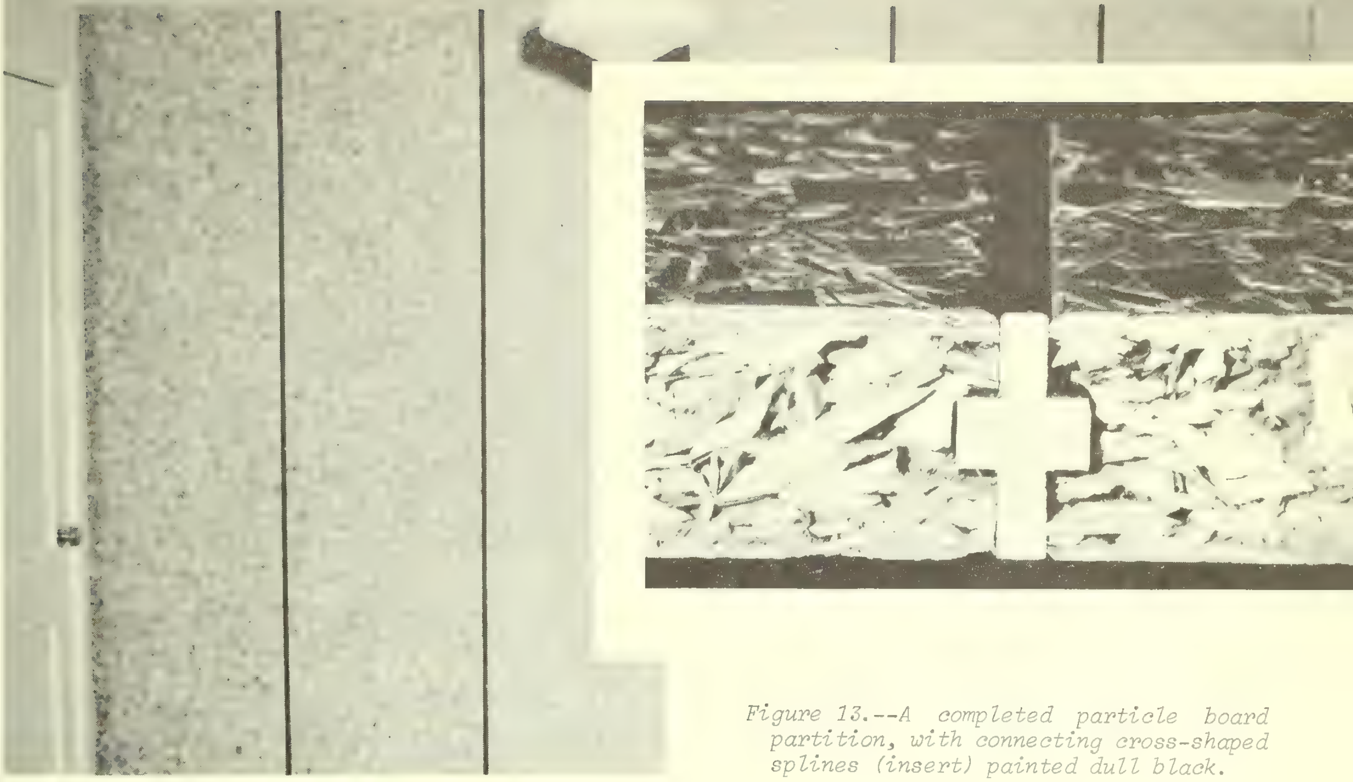

Figure 13.--A completed particle board partition, with connecting cross-shaped splines (insert) painted dull black.

Table 9.--Summary of strength characteristics of ponderosa pine particle boards[1]

Board number and description	Moisture content	Modulus of-- rupture	Modulus of-- elasticity	Tension perpendicular (internal bond)
	Percent	Lbs./sq.in.	1,000 lbs./sq.in.	Lbs./sq.in.
Standard 1/2-inch ponderosa pine boards:				
1. Planer shavings board	9.2	950	120	115
2. Shaving and flake board	8.8	2,220	280	115
3. Three-layer flake board	8.6	2,660	400	25
4. Three-layer flake and shaving board	8.7	1,960	250	135
5. FPL standard particle board	8.4	3,720	460	110
6. Two-layer flake board	8.9	3,440	465	90
7. Two-layer flake board, with phenolic binder	8.6	3,200	400	120
Comparative 1/2-inch Douglas-fir boards:				
8. FPL standard Douglas-fir board (40 lbs./cu.ft.)	8.6	4,020	570	150
Thick 1 3/4-inch chip-core boards:				
9. Three-layer chip and flake board (22 lbs./cu.ft.)	9.0	770	140	23
10. Three-layer chip and flake board, with phenolic binder (22 lbs./cu.ft.)	8.8	830	150	22

[1] Detailed description of individual boards in text. All boards, unless otherwise noted, have density of 35 lbs./cu.ft., and were manufactured with 8 percent urea binder. Data for boards 1 through 4 based on 5 test specimens taken from a single board of each type; boards 5 through 10 based on 15 test specimens, 5 taken from each of 3 boards of each type.

Comparing these minimum limits to the data shown in table 9 provides a means of judging the performance of the boards. Except for boards 1 and 3, all the 1/2-inch boards (numbers 2,4,5,6,7) met or exceeded the minimum allowable limits. Boards made under controlled laboratory conditions, however, are generally stronger in static bending and internal bond than similar boards made on a production basis. Therefore, boards 2 and 4 should also be considered marginal or unsatisfactory with respect to modulus of elasticity.

The low internal bond of board 3 is probably the result of a pressing variable such as pressure, since all failures occurred in the lower 1/16 inch of the press downside of each specimen.

The low modulus of elasticity obtained in boards 1, 2, and 4 appears to be directly related to the use of planer shavings in these boards. Within a species, static bending strength tends to increase and internal bond tends to decrease as particle shape becomes more flakelike. A flake board is in effect made up of layers that have good resistance to static bending loads. This layered effect is not so pronounced in boards containing planer shavings. Boards made with planer shavings, then, could be expected to possess good internal bond strength and only fair bending strength. Both of these properties will be further reduced if the planer shavings are excessively curled, as were the shavings used in this study. It is difficult to obtain a resin coat on the inside of the curl, consequently the adjacent faces of a compressed shaving may contain little or no resin and will weaken the board.

Board 8, representing the average of six Douglas-fir standard particle boards, was included for comparison. Except for density, they were manufactured in the same manner as ponderosa pine standard particle board 5. With density of 40 pounds per cubic foot for Douglas-fir, better strength properties are expected. Allowing for the density difference, the ponderosa pine flake boards 5, 6, and 7 compare favorably in all respects. It appears that a board comparable to Douglas-fir board can be made from ponderosa pine.

Boards 9 and 10 in table 9 are the 1-3/4-inch thick, chip-core construction. Their density of 22 pounds per cubic foot is less than that of solid ponderosa pine wood. Because of the special type of construction, they would not be expected to meet the minimum strength specifications required of standard particle board. While the strength values of these boards were not high, they seemed sufficient for the suggested uses of wall partitions and roof decking. In comparison, a commercial fiberboard roof decking, with a density of about 19 pounds per cubic foot, has a stiffness and strength in bending of about one-half the values obtained for the experimental chip-core board.

Particle board dimensional movement tests

The acceptability of particle boards for many uses, such as underlayment, core stock, and paneling is often based on properties other than strength and stiffness. "Show-through" or "telegraphing" is important in boards to be used as cores in desk tops and furniture; edge texture and screw-holding capacity are of importance in furniture applications. Of vital importance in almost all applications of particle board are the linear and thickness dimensional movements associated with changes in moisture content.

To evaluate dimensional movement properties of the test boards, 24-inch-long strips were cut from the samples. The thickness and length of these strips were accurately measured before and after exposure to ovendrying; 30 percent, 65 percent, 80 percent, and 90 percent relative humidity at 80° F.; and submersion under water. One strip was exposed to each condition after preconditioning at 30 percent relative humidity. The results of the evaluation are presented in table 10.

With the exception of board number 1, the linear movements shown in table 10 are quite small and compare favorably with standard Douglas-fir flake board 8. The thickness movements of the 1/2-inch ponderosa pine boards also compare favorably with the Douglas-fir board. Only the board composed entirely of planer shavings exhibited excessive dimensional movement. By comparison, Table 10.--Dimensional movement of ponderosa pine particle boards[1] associated with changes in moisture content

Board number and description	Change in thickness: From ovendry to soaked condition	Change in thickness: Thickness movement index[2]	Change in length: From ovendry to soaked condition	Change in length: Linear movement index[2]	Change in length: From 50 to 90% relative humidity[3]
	Percent				
Standard 1/2-inch ponderosa pine boards:					
1. Planer shavings board	34	14.6	1.72	0.81	0.54
2. Shaving and flake board	37	15.0	.46	.31	.19
3. Three-layer flake board	40	16.5	.24	.21	.04
4. Three-layer flake and shaving board	32	12.8	.32	.24	.08
5. FPL standard particle board	35	14.0	.29	.23	.06
6. Two-layer flake board	32	12.8	.29	.23	.08
7. Two-layer flake board, with phenolic binder	25	11.6	.21	.21	.06
Comparative 1/2-inch Douglas-fir boards:					
8. FPL standard Douglas-fir board (40 lbs./cu.ft.)	34	14.1	.30	.23	.05
Thick 1 3/4-inch chip-core boards:					
9. Three-layer chip and flake board (22 lbs./cu.ft.)	11	4.3	.40	.27	.17
10. Three-layer chip and flake board, with phenolic binder (22 lbs./cu.ft.)	8	3.6	.37	.28	.16

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[1] All boards, unless otherwise noted, have density of 35 lbs./cu.ft., and were manufactured with 8 percent urea binder.

[2] Based upon difference between ovendry dimension and average of dimensions at 30, 65, 80, and 90 percent relative humidity, and soaked.

[3] Maximum movement allowed under Commercial Standard specifications is 0.50 percent.

a currently available commercial flake-type particle board, designed primarily for furniture core use, has a linear movement index of about 0.05 and a thickness movement index of about 12 percent. Another commercial particle board, designed primarily for use as underlayment, has a linear movement index of 0.63 and a thickness movement index of 11 percent.

No tests were made on the sample boards to evaluate screw-holding capacity or show-through. The edge condition of the test boards, as judged by visual comparison, appears to be acceptable and comparable to commercially available boards.

Results of the dimensional movement tests indicate that flake-type particle boards properly made from ponderosa pine waste could be expected to compete with good commercial particle boards, with respect to linear dimensional movement. Thickness movement of the experimental boards is not significantly different from that of commercial boards.

The 1-3/4-inch thick chip-core particle boards 9 and 10 (table 10) exhibited extremely low dimensional movement in both thickness and length. Both thickness movement and linear movement are well below those of high-quality commercial particle boards of conventional construction.

Specimens of the 1-3/4-inch thick phenolic-bonded chip-core particle board were also subjected to six cycles of accelerated aging. No strength tests were made, but the material was observed between cycles and inspected closely after completion of the cycles. The thick material appeared to be no more affected by aging than conventional types of particle board, and perhaps less than some wood products that give satisfactory service under exterior use. The board appears to have superior qualifications for suggested uses.

The strength and dimensional movement tests performed on the conventional flake-type particle boards and the thick chip-core particle board indicate that ponderosa pine is well suited to this use. There should be no difficulty in designing particle board of ponderosa pine that could technically equal or surpass many of the currently available boards in the furniture core market and underlayment market. There appears to be a similar potential for the experimental thick board, in the partition and roof decking market.

Laminated Beams

Smaller vertically laminated beams suitable for roof beams or floor joints in conventional small building construction offer promise for effectively utilizing lower grade ponderosa pine lumber. Laminating low-grade material into conventional laminated structural timbers would not be practical nor economical. Producing vertically laminated beams made from full-length boards, however, seems to have some practical possibilities. Laminating provides an opportunity for obtaining either a random or selected distribution of strength-reducing characteristics throughout the beam. With a suitable orientation of defects, low-grade lumber can be used to produce beams of adequate strength for specified construction uses. Such beams can provide a necessary part of a coordinated component building system for use in conjunction with flooring or decking products, especially where deflection governs in design. Further, locally produced laminated members can reduce checking problems encountered when laminated members manufactured in humid regions are used in the Southwest.

Beam construction

The feasibility of vertically laminating small beams from full-length standard sizes of 4/4 low-grade lumber was investigated by making five-ply laminated joist beams from 1- by 10-inch lumber. The test lumber, all 16 feet in length, included approximately equal amounts of grades 3, 4, and 5 common (appendix A). It had previously been surfaced on two sides to a standard thickness of 25/32 inch. Some of the pieces had areas of planer skip on one or both faces.

Boards were randomly selected for 10 beams; grade 3 common boards were assigned to the outer beam faces for appearance. Inner laminations were of grades 4 and 5 common; laminations two and four were of a like grade.

The laminations of beams 1 through 5 were left exactly as they occurred in random layup. No attempt was made to improve defect orientation.

In beams 6 through 10, the randomly selected boards were reoriented or interchanged so that strength-reducing characteristics would be distributed in a position judged to have the least effect on bending strength and stiffness. Grade 3 common boards were retained on the outer faces. The best edge of each board was placed downward, toward the tension side of the beam. It was intended that the results obtained in testing this group, when compared to the group made up of beams 1 through 5, should provide an indication of the value of such reorientation.

After selection of the material for the first 10 beams, 7 randomly selected boards remained. The five poorest boards remaining were assigned to beam 11, and were oriented to concentrate the knots along the tension side of the beam. The outer or face laminations were grade 5 common, and the inner three laminations were grade 4 common. The beam was laid up in this manner to gain some idea of the worst condition that might occur in purely random layup.

The laminations of each beam were laid out in order, graduated at 4-foot intervals, numbered with beam and lamination number, and marked to indicate designated tension edge (fig. 14). Both faces of each lamination were photographed, as a record of defect location within the beam. The beams were dead piled and covered until glued.

The stresses applied on the glue lines of vertically laminated beams by external loads are normally appreciably less than on glue lines of horizontally laminated beams. Therefore, exacting glue-laminating procedures are of lesser importance. The boards had been surfaced at the mill prior to shipment to the Laboratory. To simulate economical production procedures, the boards were glued into beams without further surfacing. The beams would presumably be handled as stock lumber yard items, and would perhaps be exposed to the weather, both in the yard and in subsequent use. Consequently, a room-temperature-setting phenol-resorcinol adhesive suitable for exterior exposure was specified.

Further economy in laminating was simulated by applying glue to both surfaces of laminations 2 and 4 only, as is done in making conventional plywood (fig. 15). These two laminations were double-spread by passing them through a double-roll 18-inch glue spreader. The remaining laminations (1, 3, and 5) were not spread at all. Many of the boards were slightly cupped and warped, which caused the glue-spread to vary from place to place on the board. In beams 3 through 11, the spread laminations were passed through the spreader twice to obtain more uniform ad-

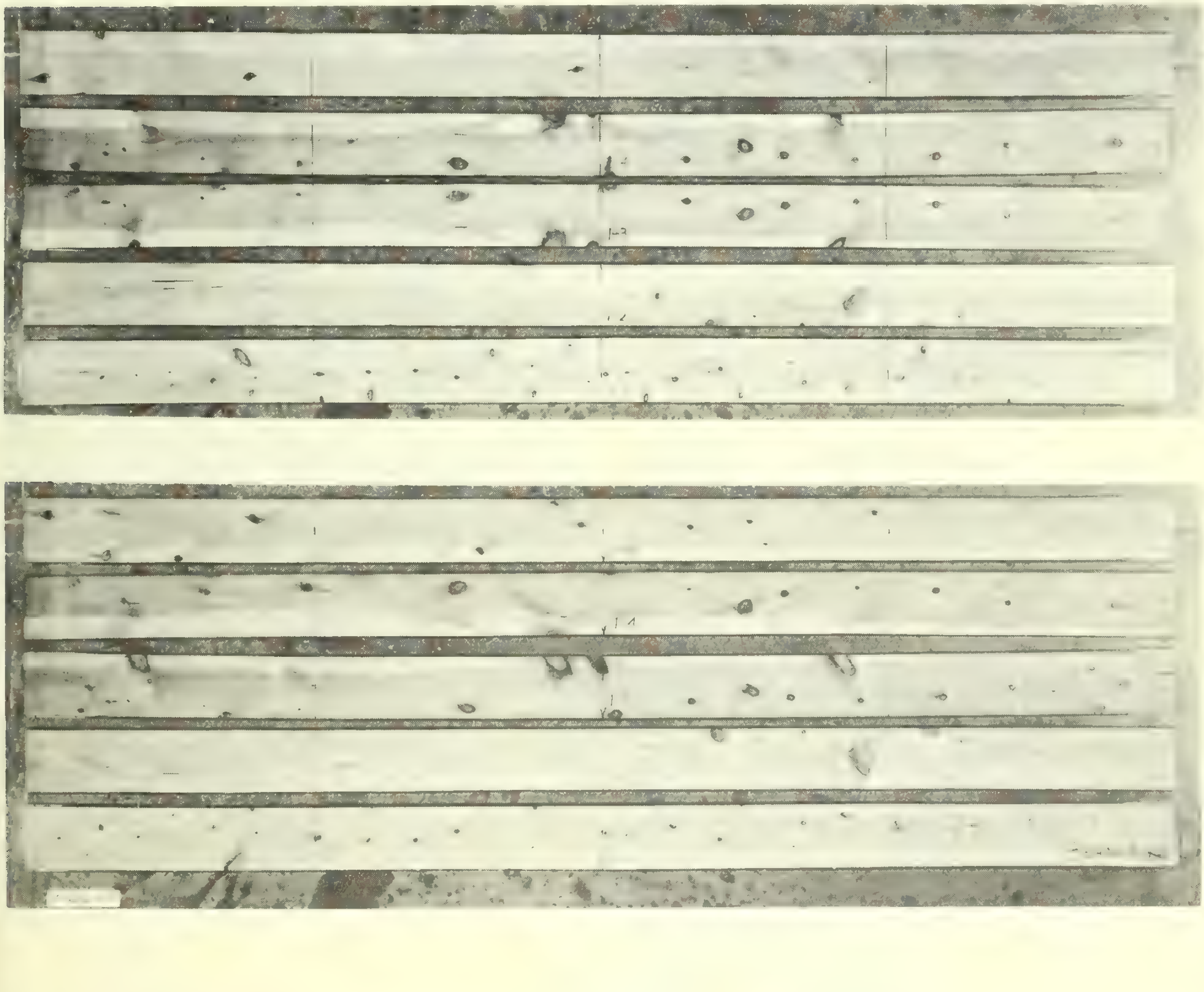

Figure 14.--These lower grade boards made up the laminations of a typical beam. The composite photo shows both front and back of all five laminations.

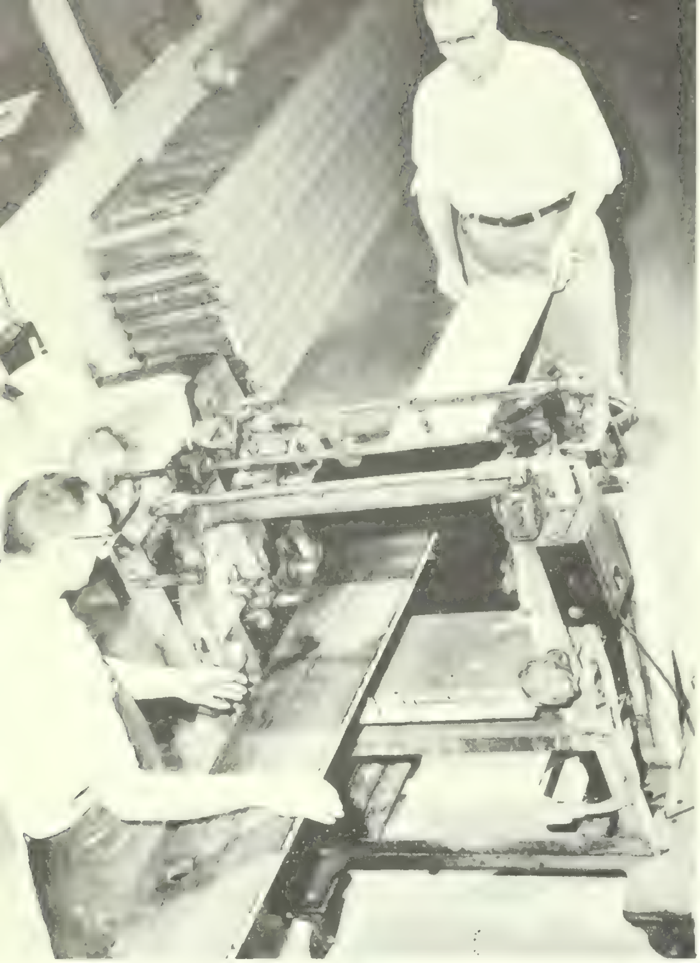

Figure 15.--Second and fourth laminations of the beams were double-spread with phenol-resorcinol adhesive, in a double-roll spreader equipped with doctor rolls.

hesive coverage. The average spread for all beams was estimated at 40-45 pounds per M square feet of glue-joint area.

Areas of complete planer skip did not spread well at all. Areas of partial skip, from which the roughest surface had been removed, spread without difficulty.

The beams were laid up in pairs in a hand clamping jig, between 2- by 12-inch caul boards. Side clamps were used to align the laminations and remove bow while pressure was applied (fig. 16). Side clamping was hampered by variations in the width of the surface-two-sides (S2S) laminations. Laminations of uniform width would prove a definite advantage.

Pressure clamps were located on approximate 8-inch centers along the length of the 16-foot beams. The clamps were uniformly loaded with a torque wrench to apply approximately 150 pounds per square inch glue-line pressure.

Total assembly time for the beams averaged approximately 25 minutes, of which less than 5 minutes was open assembly time. The beams remained in the clamps at room temperature for a minimum of 18 hours. After the clamps were removed, the beams were allowed to cure for 3 weeks in a controlled atmosphere at 73° F. and 50 percent relative humidity. The beams were then dressed to a uniform depth of 9-1/2 inches. Each beam was slightly over 3-7/8 inches wide, 9-1/2 inches deep, and 16 feet long.

Beam tests and evaluation

All beams were tested in static bending to determine strength and stiffness characteristics. The beams were simply supported over a span of 15 feet and subjected to two-point loading with load points 5 feet apart (fig. 17). The results of these tests for the 11 beams are shown in table 11.

For comparative purposes, average values for clear straight-grained ponderosa pine at

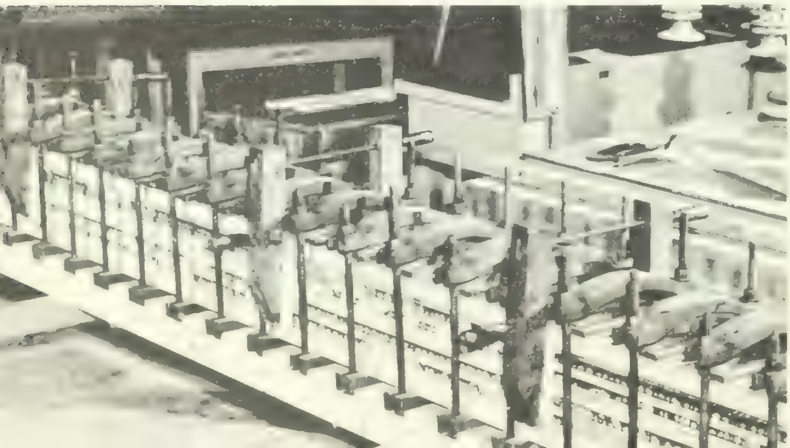

Figure 16.--Immediately after a beam was laid up, side clamps were applied to align the edges of laminations and remove bow. Pressure clamps were then applied to the beams at 8-inch intervals.

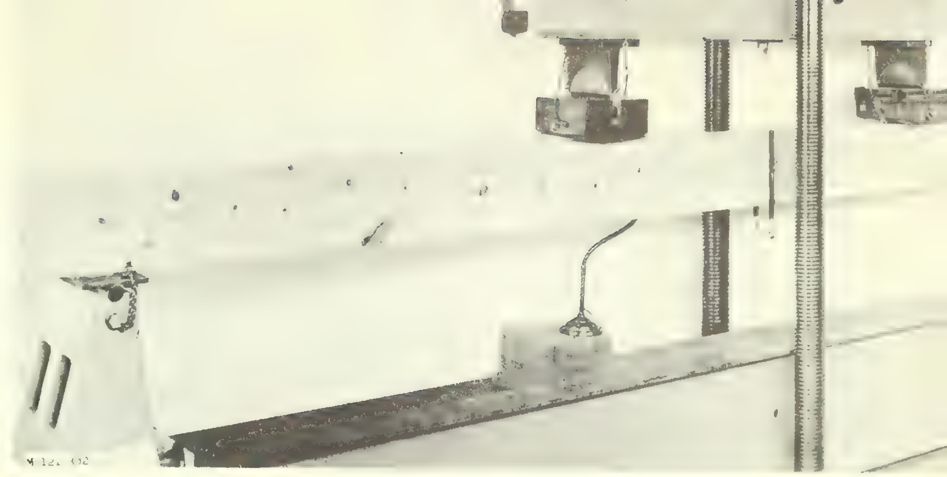

Figure 17.--A test beam positioned in a screw-type testing machine.

Table 11.--Physical characteristics of vertically laminated 16-foot beams made of low-grade ponderosa pine

Beam No.	Width	Depth	Weight	Moisture content[1]	Specific gravity[2]	Modulus of elasticity	Stress at proportional limit	Modulus of rupture	Corrected modulus of rupture[3]
	Inches		Lbs.	Percent		1,000 lbs./sq.in.	- -	Lbs./sq.in.	- -
GROUP 1 -- RANDOM SELECTION AND LAYUP									
1	3.93	9.51	126.5	9.9	0.44	1,160	2,280	3,570	3,100
2	3.91	9.51	135.5	13.1	.46	1,240	2,550	3,930	3,190
3	3.93	9.52	135.0	11.4	.47	1,080	2,020	3,140	2,470
4	3.93	9.54	131.0	10.2	.46	1,180	3,520	4,240	3,440
5	3.95	9.52	128.2	10.7	.44	1,100	3,270	3,950	3,420
Average				11.1	.46	1,150	2,730	3,770	3,120
GROUP 2 -- RANDOM SELECTION WITH SPECIAL ORIENTATION IN LAYUP									
6	3.92	9.52	129.5	10.8	.45	1,110	3,290	5,740	4,810
7	3.91	9.51	124.5	11.4	.43	1,080	2,550	4,410	3,960
8	3.92	9.52	124.5	10.9	.44	1,210	3,800	5,440	4,720
9	3.93	9.51	132.2	11.1	.46	1,340	3,800	5,340	4,330
10	3.88	9.54	120.0	11.7	.42	1,200	3,060	4,540	4,220
Average				11.2	.44	1,190	3,300	5,090	4,410
SPECIAL BEAM									
11	3.92	9.54	145.0	12.2	.50	1,030	3,030	4,170	2,980
Overall average				11.2	.45	1,160	3,020	4,410	3,690
Species average[4]				12.0	.40	1,260	6,300	9,200	9,200

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[1] Based on sample sections 1 inch long and free of knots; expressed in terms of ovendry weight.

[2] Based on volume of beam at test and estimated ovendry weight of beam.

[3] Corrected to a specific gravity of 0.40.

[4] Taken from: Markwardt, L. J., and Wilson, T. R. C. Strength and related properties of woods grown in the United States. U. S. Dept. Agr. Tech. Bul. 479 (face p. 4). 1935.

12 percent moisture content are shown at the bottom of the table.

Beam 11 was laid up to obtain a heavy concentration of strength-reducing characteristics on the tensile side, thus approximating the worst condition that could occur in random layup. The beam was inadvertently tested with the best, however, rather than worst, edge on the tensile side. The modulus of elasticity was still the lowest of any of the beams tested, indicating that this property is affected by grade of laminations.

The data in table 11 indicate that the strength of beams made by vertically laminating boards of low quality can be increased significantly by selective orientation of the laminations. Dispersing strength-reducing characteristics and placing the poorer edges of the boards on the compression side of the beam result in a substantial increase in stress at proportional limit and modulus of rupture. The average modulus of rupture for the second group of beams is about 35 percent higher than that for the random layup group. Furthermore, the minimum modulus of rupture value in the second group is higher than the maximum value in the random layup group.

A selective orienting procedure in production would require that top and bottom of the beams be positively identified to prevent improper installation. If they were inadvertently placed upside down, their bending strength could be one-half or less of that expected with proper placement.

Failure of all beams during the bending tests started in the wood in an area adjacent to knots or cross grain, on the tension side of the beam. There was no evidence that weak glue bonds contributed to the initial failure. The gluing procedures used in constructing the test beams appear to provide a glue bond of adequate strength for the purpose intended.

The glue bond should also be sufficiently durable to withstand stresses due to environmental conditions to which the member will be exposed. To evaluate durability of the glue bond, a cross section was cut from each beam and subjected to delamination tests. The results of the delamination tests were generally satisfactory; some delamination was observed in resinous areas of the beams, however, and appeared to be directly associated with the presence of resin.

The results of the beam-strength tests and glue-bond tests lead to the conclusion that the gluing techniques used, and the glue spread of 40-45 pounds per M square feet, are adequate for the product. They are close to minimum for acceptable performance, however. The delamination tests further indicate that boards with relatively large areas of heavy resin should be culled from laminating stock.

Average specific gravity of the beams was 0.45 as compared with an average value of 0.40 reported for the species. A second evaluation of specific gravity, from only clear wood specimens, confirmed the 0.45 value. If the average specific gravity of the beams had been 0.40 and all other factors were the same, somewhat lower values of strength and stiffness would be expected. Values of modulus of rupture corrected to a specific gravity of 0.40 were calculated for each beam, and are shown in the last column of table 11.

Vertically laminated beams of the type evaluated have been suggested for use as floor joists spaced on 4-foot centers. Deflection limitations rather than strength frequently govern in design of such structures. For floor systems, the deflection is often limited to 1/360 of the span. If such a deflection limit, a total floor load of 40 pounds per square foot, and 4-foot spacing are assumed, the strength and stiffness of the beams appears to be adequate for spans up to about 13 feet.

The results of the evaluation are too limited to provide a basis for design recommendations. However, beams of the size, type, and construction evaluated show definite promise of being practical for use in floor and roof systems in housing and other building construction. The strength of such beams can be increased significantly by the selective orientation of defects during production.

Overlaid Siding

Overlaying lumber with fiber sheet products offers utilization possibilities for low-grade ponderosa pine. Of particular interest in this study was the possibility of using selective cuttings from mill-run grade 3, 4, and 5 common lumber to produce overlaid products of exceptional quality and surface appearance. Overlaid products with a higher market value than sheathing were emphasized, since they can better withstand the costs of selective cutting and processing.

For the utilization of low-grade 4/4 and 5/4 lumber, two Laboratory-developed siding products were considered: a combination siding-sheathing product from 4/4 lumber, and a resawn beveled siding product from 5/4 lumber. Both were produced from the 4/4 and 6/4 rough test lumber supplied.

A rather wide range of overlay materials for wood has been developed on an experimental basis in recent years. Selection of the correct overlay material for the design and type of product and ultimate end use is extremely important. The two overlaid siding products manufactured from ponderosa pine presented somewhat different requirements for overlay material. The combination siding-sheathing product, because of the exposure conditions encountered in its use, required overlaying on both front and back. An overlay that restricted dimensional movement was considered desirable. In addition, the siding was end and edge matched with tongue and groove, and was beveled to create a drip edge and shadow line. The overlay material used in such an application should, therefore, machine well and cut cleanly without fraying. The overlay material specified for this siding was made at the Laboratory from kraft pulp blended with 15 to 18 percent of water-dispersible phenolic resin at the beater. The included resin adds tensile strength and durability to the overlay, and provides desirable machining characteristics. Prior to use, the overlay material was fully cured in a steam-heated press at 300° F.

The overlay described is considerably more stable dimensionally in the machine direction than in the cross-machine direction. Consequently, for maximum restraint of dimensional movement of the siding, the machine direction of the overlay should be at right angles to the direction of grain in the lumber. This requires overlay material as wide as the length of the siding. If overlay material of this type is locally manufactured, but in inadequate widths, dimensional stability in the cross-machine direction can be increased through the use of expander rolls on the paper machine. The curved expander rolls exert a sidewise pull on the fiber web, and restrain it from shrinking as it dries. The resulting overlay has improved dimensional stability in the cross-machine direction, and performs well when applied lengthwise to the lumber.

The second siding product manufactured, a resawn beveled siding, could be overlaid on the weather face only, because of the method of manufacture. In addition, a single-face overlay was considered adequate for the end use contemplated. The product, therefore, required an overlay material that would not restrain dimensional movement of the wood, and would produce an essentially stress-free construction when applied to only one side. For this product, 0.005-inch vulcanized fiber overlay was specified. The vulcanized fiber used as an overlay is essentially unsized, unloaded paper that has been treated with zinc chloride solution. This material has dimensional movement characteristics across the machine direction quite similar to those of wood in the tangential direction; therefore it can be used effectively in a single-face application. Specific orientation of the machine direction of the fiber sheet with grain direction of the siding is necessary. Like vulcanized fiber, parchmentized paper also performs satisfactorily as a single-face overlay.

Combination siding-sheathing production

The 4/4 rough test lumber for the combination siding-sheathing was random-width material 12 feet long. Moisture content of the stock ranged from 8 to 10 percent, a satisfactory compromise for ultimate use either in the Southwest or at Madison, where moisture content of wood in use may range from 8 to 12 percent. For use specifically in the Southwest, lumber stock probably should not exceed 8 to 9 percent moisture content when processed.

The lumber was surfaced on the best face, at a 15/16-inch planer bed setting, to obtain a working face and a relatively uniform thickness. In commercial production, it would be desirable to joint this working face rather than plane it, to circumvent cupping in wider stock.

All lumber was edge jointed and ripped random width for recovery of material suitable for overlaying. The material was ripped to obtain the widest possible pieces; the recovery included pieces from 1-1/2 to 10 inches wide. Lumber that could be used full width was trimmed and jointed to obtain straight, parallel edges.

Material judged suitable for overlay included knots of any size, so long as sound and not deeply chipped. Pitch seams, pitch pocket, stain, borer holes up to 1/16 inch across, open defects up to 1/32 inch wide, and open defects requiring plugs up to 2 inches in diameter were allowed on the face side. More open defect, including chipped knots, borer galleries up to 1/4 inch by 1 inch, slight wane edge, and machine gouge, was allowed on the back side.

End gluing was not attempted with the 4/4 material; consequently, cross cutting for added recovery was not considered. It is believed, however, that cross cutting and end gluing would not have appreciably increased the recovery.

Recovery from each grade of 4/4 test lumber is shown in table 12.

The ripped material was laid up in panel widths equal to three siding widths (fig. 18), and edge glued with a phenol-resorcinol resin glue. The working face of each panel was used as a reference surface to obtain flush alignment of the pieces. The panels were clamped in hand clamps for a period of 18-24 hours, at a room temperature of approximately 70° F. (fig. 19).

Table 12. --Recovery of overlaid combination siding-sheathing from 4/4 common lumber

Lumber grade	Initial volume	Rip loss		Panel volume	Manufacture loss[1]		Rough siding	Finished siding[2] coverage
	Bd. ft.	Bd. ft.	Pct.	Bd. ft.	Bd. ft.	Pct.	Bd. ft.	Sq. ft.
3	266	30	11.3	236	13	4.9	223	208
4	268	50	18.7	218	21	7.8	197	183
5	262	98	37.4	164	21	8.0	143	132
Total	796	178	22.4	618	55	6.9	563	523

[1] Attributable to kerf losses, panel trim loss, open glue joint, overlooked defects, etc.
[2] Based on 8-inch by 8-foot face coverage per piece.

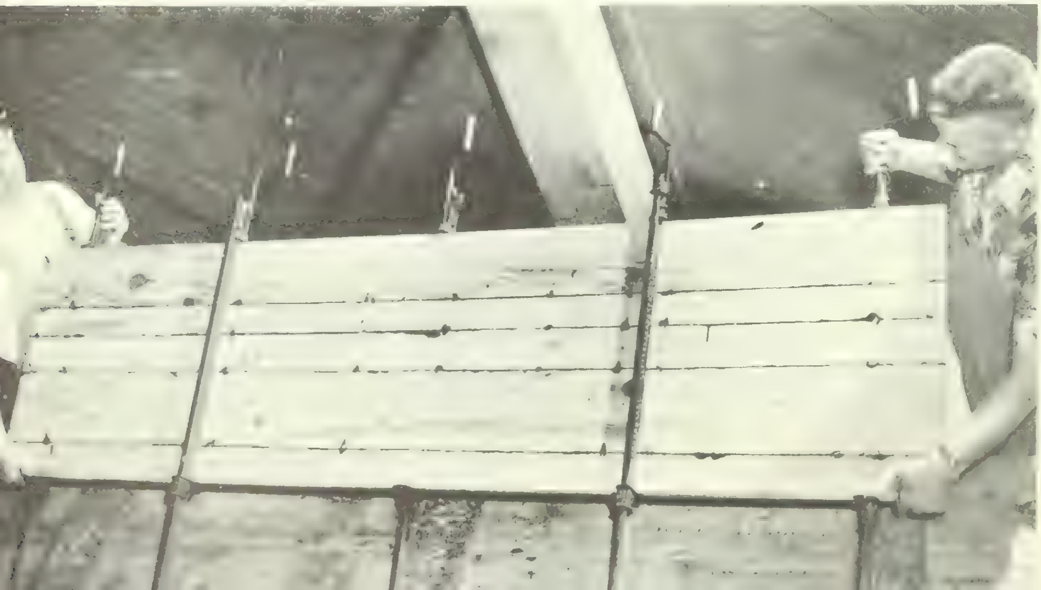
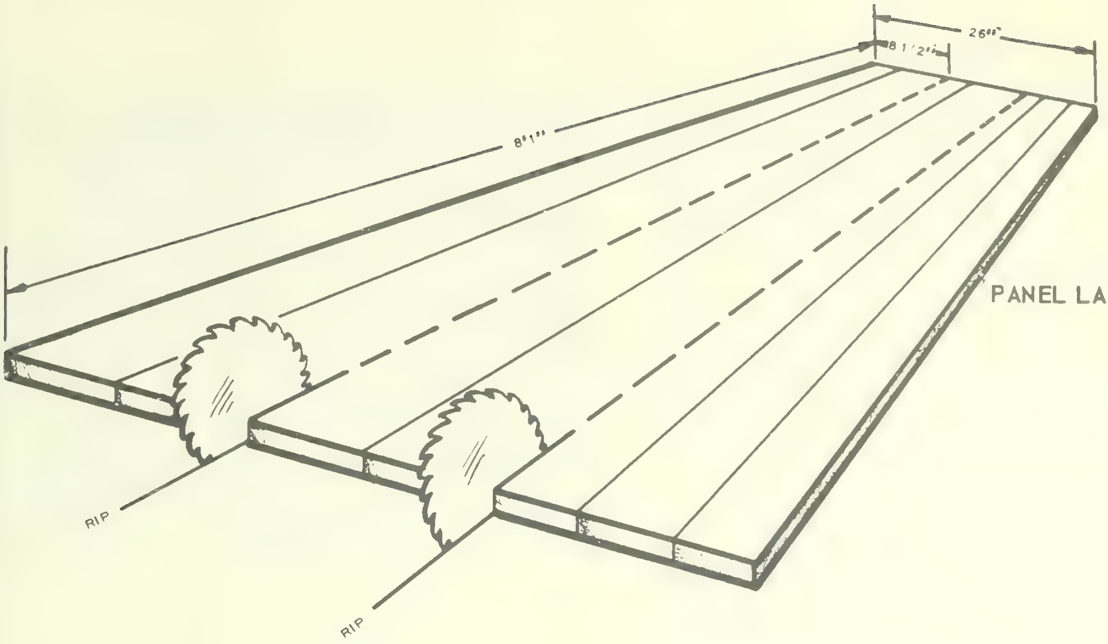


Figure 19.--Edge-glued panels of [illegible] hand clamped for 18 to 24 hours.



PANEL LAYUP DETAIL

CONSTRUCTION SPECIFICATIONS

(1) PANEL OF EDGE-GLUED RANDOM-WIDTH STOCK:

STOCK TO HAVE ONE SOUND FACE, LIMITED

OPEN DEFECT ON REVERSE.

(2) ROUGH PANEL SIZE 26 INCHES BY 8 FEET 1 INCH.

(3) FINISHED THICKNESS 11/16 INCH.

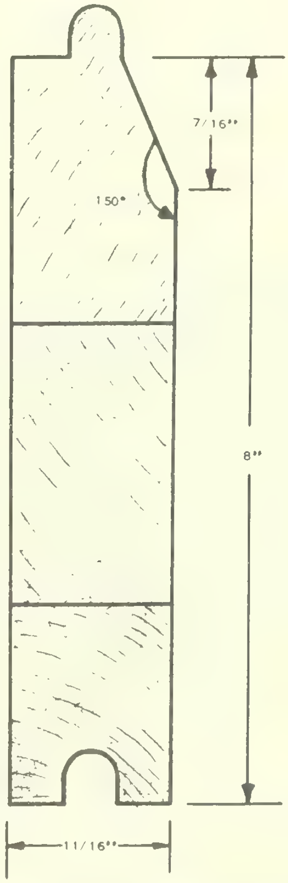
(4) OVERLAY BOTH SIDES WITH KRAFT SHEET,

PHENOL RESIN ADHESIVE, COLD PRESS.

(5) RIP TO 8½ INCH ROUGH WIDTHS.

(6) END AND EDGE MATCH AND BEVEL 30 DEGREES

TO FORM DRIP EDGE.



CROSS-SECTION SIDING DETAIL

Figure 18.--Manufacturing specifications developed for overlaid combination siding-sheathing.

The cured panels were surfaced to a finished thickness of 11/16 inch. A minimum cure time of 3 to 4 days is recommended before final surfacing of glued panels to prevent subsequent sunken glue joints. Panels that are appreciably warped or cupped may need to be rough ripped and face jointed in siding widths to relieve cupping.

A few open defects purposely left in the panels were drilled out and plugged with friction plugs. With the proper equipment for plugging, the process appears to be worthy of consideration for commercial application.

Since laboratory equipment limitations prohibited overlaying the material in full panel widths, all panels were first ripped into rough siding widths of 8-1/2 inches. Each piece of rough siding was numbered and photographed to provide a permanent record of defects and defect location (fig. 20). The photographs can be used to determine the location of specific defects under the overlay sheet.

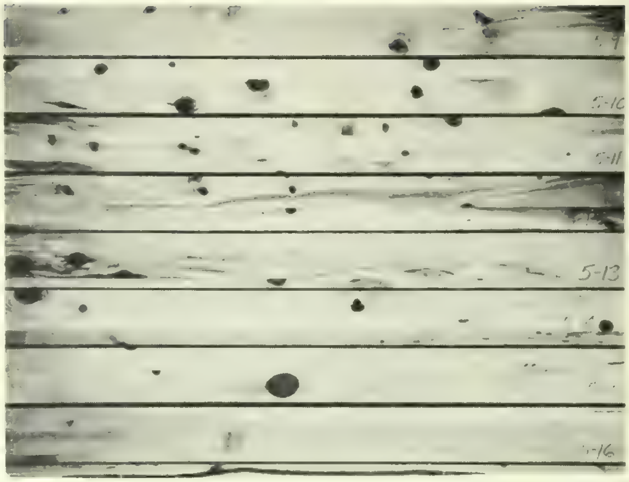


Figure 20.--The rough-sized edge-glued siding stock was photographed to provide a record of defect location.

The completed rough-width siding stock was overlaid front and back with the resin-impregnated kraft overlay material previously described. The stock was double spread through a standard 18-inch roller spreader with an acid-catalyzed phenol resin adhesive at a spread of 30-35 pounds per M square feet of glue line. The overlay sheets were applied to each side, and the siding was placed in a cold press under 100 pounds per square inch pressure for 4 or more hours.

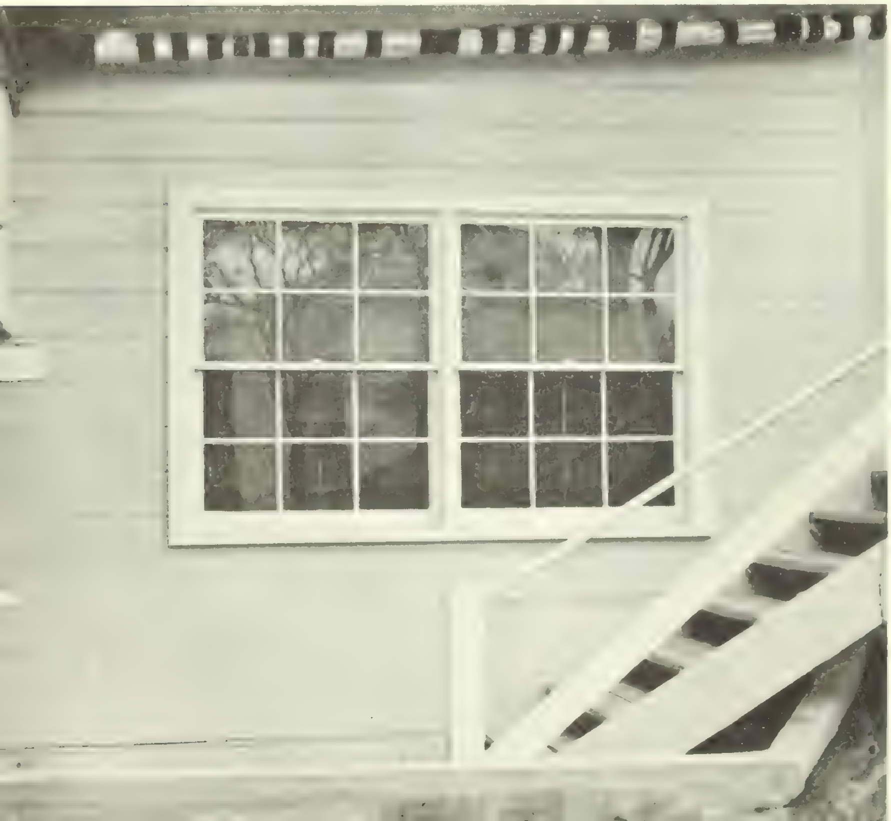


Figure 21.--Overlaid ponderosa pine siding-sheathing makes up part of the wall of a recently constructed Forest Products Laboratory building.

The overlaid stock was edge and end matched with standard tongue and groove to a face dimension of 8 inches wide by 8 feet long. A 7/16-inch bevel (approximately 30°) was extended from the base of the tongue to the weather face (fig. 18) to provide some drip-edge and shadow-line effect (fig. 21).

In commercial production, many of the procedures used here could be automated or bypassed. The use of straight-line rip saws would eliminate the need for edge jointing layup stock. Material could go from rip saw directly to automated edge-glue equipment. Mechanical restraint applied to the faces of panels during edge gluing would help obtain flush alignment of the boards in panels. Edge-glued panels could be overlaid before being ripped into rough siding widths.

Resawn beveled siding production

The resawn beveled siding proposed for the study was designed to utilize 5/4 common lumber efficiently, rather than the 6/4 lumber provided. Consequently, the loss in volume experienced was considerably greater than would occur normally with 5/4 stock.

The rough 6/4 test lumber available was random-width material 12 feet long. A check of moisture content showed averages of 10 percent on the surface and 14 percent at the center of the stock. Both center and surface readings ranged up to 3 percent above and below the averages. Since the material was ultimately to be resawn, the 4 percent moisture gradient was considered excessive and likely to distort the resawn material. The overall range of moisture content was also greater than desirable. To reduce the variation in moisture content, reduce moisture gradient, and relieve any severe casehardening, the material was equalized and conditioned in a kiln according to the schedule shown in table 13.

After conditioning, sections were cut from each kiln sample for stress determination. The samples exhibited very slight casehardening, a desirable condition since up to 1/4 inch of material would be removed from each face of the stock during siding manufacture. Average moisture content of the stock after conditioning was 9.1 percent, with a spread of 0.7 percent among six samples.

The material was surfaced on two sides, reducing the thickness to 1-3/8 inches, to facilitate further processing. Had the material been 5/4 lumber, only one working face would have been surfaced initially. Pieces with any tendency to cup were face jointed prior to surfacing to thickness, since cupping could ultimately create resawing problems. In commercial production, it would be desirable to joint the working face of all material.

All material was edge jointed, then random-width ripped and cross cut for recovery of material suitable for overlaying. The recovery included pieces from 2 to 12 inches wide, and from 18 inches to 8 feet long.

The criteria employed in determining allowable defect in the panels were essentially the same as used in judging the 4/4 material.

Table 13.--Equalizing and conditioning schedule for 6/4 ponderosa pine[1]

		Dry bulb temperature	Kiln equivalent moisture content
	Percent	Degrees F.	Percent
WHEN:			
Desired final	10	--	--
Start equalizing when driest sample reaches	8	160	8
Stop equalizing when wettest sample reaches	10	--	--
Condition at	--	170	13

[1] Source: U. S. Forest Service, Forest Products Laboratory. Detection and relief of casehardening and final moisture content tests in kiln-dried lumber. FPL Tech. Note 213, 6 pp. Dec. 1958.

Table 14.--Recovery of overlaid resawn beveled siding from 6/4 common lumber

Lumber grade	Initial volume	Cutting loss		Rough panel volume	Manufacture loss[1]		Rough siding	Finished siding[2] coverage
	Bd. ft.	Bd. ft.	Pct.	Bd. ft.	Bd. ft.	Pct.	Bd. ft.	Sq. ft.
3	222	52	23.4	170	12	5.4	158	171
4	204	98	48.0	106	12	5.9	94	102
5	222	116	52.3	106	14	6.3	92	100
Total	648	266	41.0	382	38	5.9	344	373

[1] Attributable to kerf losses, panel trim loss, overlooked defects, etc.

[2] Based upon 1-1/2 inch overlap on installed siding, or 8-inch by 8-foot face coverage per piece.

Defects that would require plugging, however, were not allowed. Also, since both overlaid surfaces became weather faces in the finished product, requirements were the same for both faces.

Recovery from each grade of 6/4 test lumber is shown in table 14.

The board foot volume losses reflected in table 14 are comparatively large for two reasons:

1. The use of 6/4 material entailed starting with thicker test lumber than could efficiently be utilized by the siding pattern.
2. The material was similar to shop-grade lumber--large defects extending the full width of the piece--with short clear sections between. Much better recovery could be obtained from typical Common grade lumber. Much of the grade 3 test lumber approached a more typical Common grade 3, a fact reflected by the improved recovery from that grade.

The ripped and cross-cut material was laid up in panel widths equal to two siding widths (fig. 22). Full-length pieces were laid at each edge and at the rip line of the panel, with end-glued courses interspersed between. A double tongue-and-groove end joint was employed in end gluing the short stock. The joint facilitates end gluing, provides a smoother panel face by holding the pieces in alignment, and provides an added degree of strength in the completed panel.

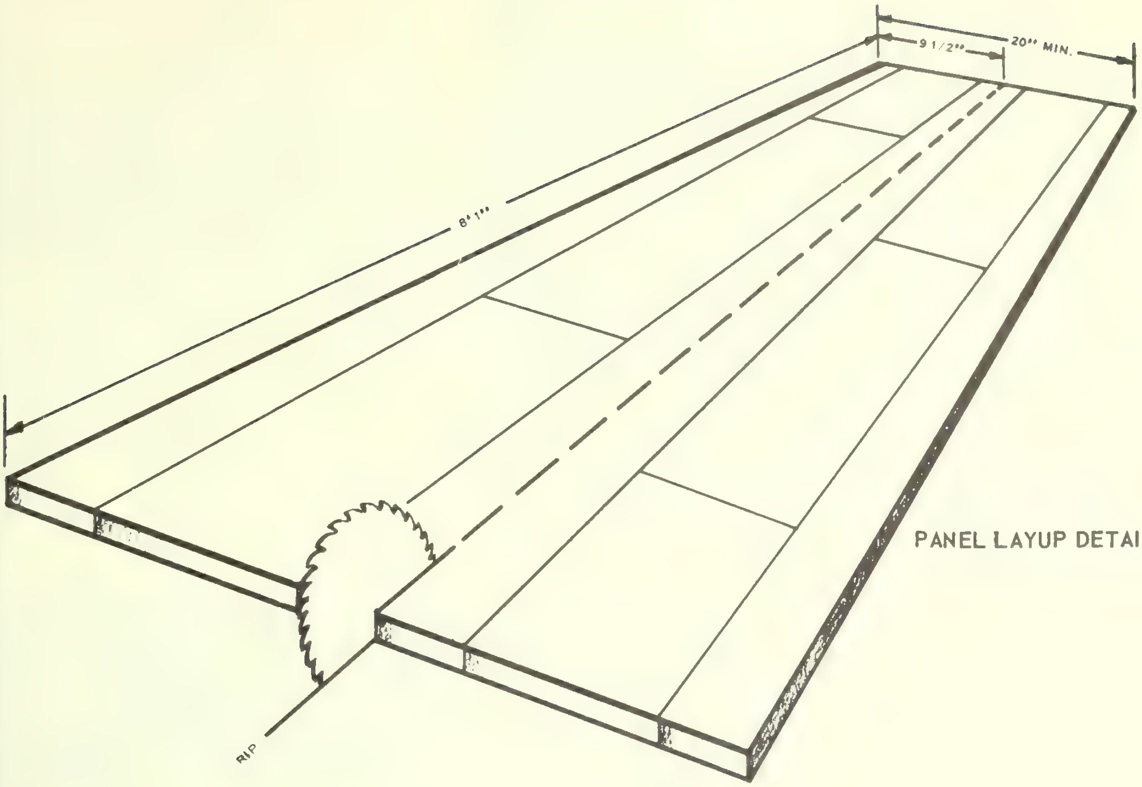
The panels were end and edge glued with a phenol resorcinol resin glue and clamped in hand clamps for a period of 18-24 hours, at a room temperature of approximately 70° F.

The cured panels were surfaced to a finished thickness of 1-1/16 inches. Equipment limitations prohibited overlaying the material in panel widths; consequently, all panels were ripped into rough-siding widths of 9-3/4 or 10 inches prior to overlaying. Each face of the double-thickness siding stock was numbered and photographed as a permanent record of defect location. Typical siding stock, before overlaying, is shown in figure 23.

The completed double-thickness siding stock was overlaid on both faces with the vulcanized fiber overlay material previously described. The stock was double spread through a standard roller spreader with an acid-catalyzed phenol resin adhesive at a spread of 30-35 pounds per M square feet. Overlay sheets were applied to each face, and the overlaid stock was cold pressed at 100 pounds per square inch for 4 or more hours.

The overlaid stock was end matched with a double tongue and groove (fig. 24), spaced to allow a single tongue and groove to remain on each piece of resawn siding. A 10-degree bevel was machined on each longitudinal edge to provide an undershot drip edge (fig. 22). The stock was resawn on a vertical band resaw, canted to produce the correct bevel in the finished product.

Again, much of the procedure employed in manufacturing this product could be simplified and automated in commercial production.



PANEL LAYUP DETAIL

CONSTRUCTION SPECIFICATIONS

(1) PANEL OF END- AND EDGE-GLUED RANDOM-SIZE STOCK: CONTINUOUS LENGTHS ALONG EDGES AND RIP LINE.

(2) STOCK TO HAVE TWO SOUND FACES.

(3) ROUGH PANEL SIZE 20 INCHES BY 8 FEET 1 INCH.

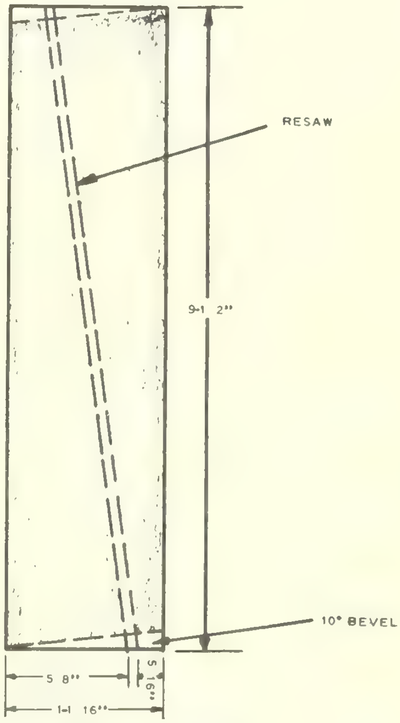
(4) FINISHED PANEL THICKNESS 1-1/16 INCHES.

(5) OVERLAY BOTH SIDES WITH VULCANIZED FIBER, PHENOL RESIN ADHESIVE, COLD PRESS.

(6) RIP TO 9¾-INCH ROUGH WIDTHS.

(7) BEVEL EDGES 10 DEGREES: END MATCH WITH DOUBLE TONGUE AND GROOVE.

(8) RESAW STOCK INTO BEVELED SIDING PATTERN.



CROSS-SECTION OF STOCK: RESAW AND BEVEL DETAIL

Figure 22.--Manufacturing specifications developed for overlaid resawn beveled siding.

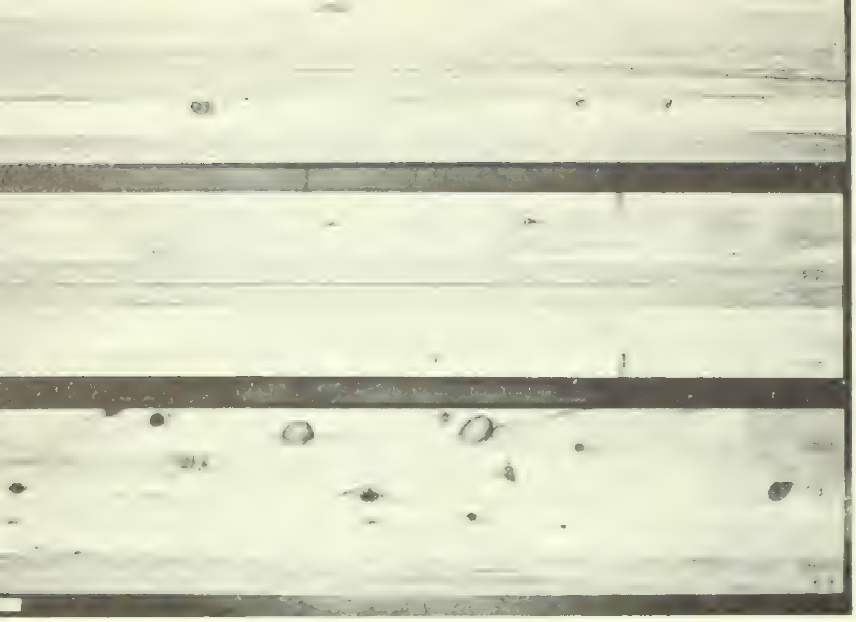


Figure 23.--The double-thickness siding stock was photographed from both sides before it was overlaid to provide a record of defect location.

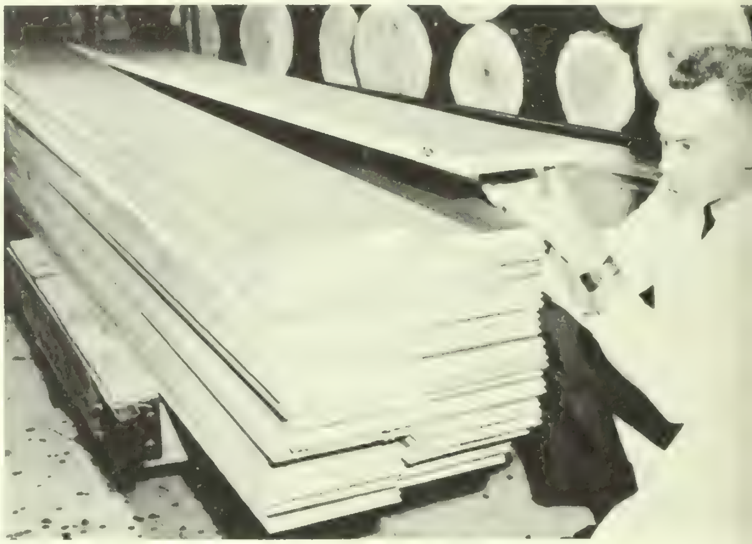


Figure 24.--The overlaid double-thickness siding stock is inspected before being resawn into standard beveled siding. Overlaid stock is end matched with a double tongue and groove spaced to allow a single tongue and groove to remain on each piece of resawn siding.

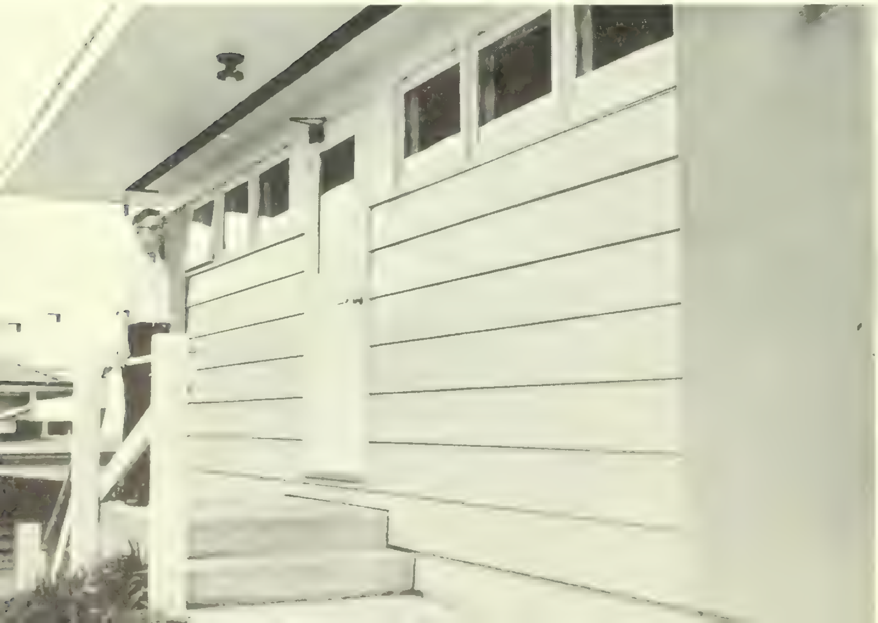


Figure 25.--Overlaid bevel siding is also in use on exterior of a new Forest Products Laboratory building.

Overlaid siding evaluation

Both overlaid siding products were manufactured without difficulty with very basic equipment. Much of the equipment used was improvised, or was designed for laboratory experimentation, and was much less suitable for the job than would be properly designed commercial equipment. Gluing and pressing procedures, and the overlays used, appeared to perform well and to provide a durable product (fig. 25). No major technological obstacles are foreseen in the commercial production of either type of overlaid siding.

The manufacture of overlaid products offers particular advantages to the sawmill industry because it can readily be integrated with sawmill operation. The necessary equipment requires a relatively modest capital investment, and is suitable for the manufacture of certain other cold-press laminated products as well. Automated selective cutting equipment and electronic end-and-edge glue equipment is becoming commonplace and available in units adaptable to relatively small production.

Experimental overlaid siding products have been exposed on test fences, and in service on buildings, at the Forest Products Laboratory for a number of years.[11] Overlays such as those used in the study have exhibited excellent resistance to deterioration, paint-holding ability far superior to wood, and high resistance to impact damage from hail stones or similar objects.

In addition to siding products, other overlaid products should also be considered. Overlaid panels in sizes of 2 feet by 8 feet or larger could perhaps find a substantial market for shelving, cabinet backing and interiors, and other construction uses where sheathing-grade materials are unsuitable. With a selective cutting process, a high-grade, clear, non-overlaid panel product may also be feasible.

Laminated Flooring

Two laminated flooring products appeared to offer considerable promise in utilizing low-grade ponderosa pine lumber and veneer. The two products specifically considered for demonstration and evaluation include a three-ply lumber-core combination subfloor and underlayment, and a two-ply lumber-base finished flooring. These products utilize lower grades of lumber in 5/8-inch and 25/32-inch thicknesses. In addition, lumber-core flooring would utilize ponderosa pine face and back veneers. Both products would be well suited for inclusion in a coordinated component construction system.

Lumber-core laminated flooring was conceived as a dual-purpose product, combining the functions of subfloor and underlayment in a single panel. It would thus serve the same functions as commercially available combination subfloor-underlayment products currently in wide use. Initial computations indicated that a panel using standard 25/32-inch lumber as a core, with face and back plies of pine veneer approximately 0.234 inch thick, would match the stiffness of commercial dual-purpose plywoods. Consequently, demonstration panels were constructed from grades 3, 4, and 5 common 25/32-inch lumber, and ponderosa pine veneer initially cut 3/10 inch thick, as previously discussed. Since particular interest had been expressed in using 4-foot veneer, the product was designed to span a single joist opening, with joists or beams placed on 4-foot centers. This would allow production of an 8-foot by 4-foot panel from 4-foot veneer, with the 8-foot panel dimension parallel to the joists. Tongue-and-groove matching on the unsupported or 4-foot ends was added to eliminate the need for blocking.

A finished flooring product, called Flex-floor, was developed by the Forest Products Laboratory several years ago to utilize low-grade softwood lumber. Flex-floor consists of a 1/8-inch hardwood face veneer cross laminated to a low-grade softwood backing of 5/8-inch lumber. The backing is grooved by sawing kerfs at frequent intervals to give the material a degree of flexibility. The product can be made in rather large sections, and can be V-grooved to simulate random-width planking. It is particularly well suited to laying on concrete with an adhesive, a feature that should prove attractive in the concrete-slab type construction common in the Southwest.

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[11] *Fleischer, H. O., and Heebink, Bruce G. Overlays for lumber--an old product in a new dress. U. S. Forest Serv. Forest Prod. Lab. Res. Note 035, 11 pp., illus. April 1964.*

Lumber-core flooring production

The lumber-core subfloor-underlayment panels constructed for demonstration and testing purposes were made 48 inches long and 40 inches long (rather than 8 feet) to facilitate manufacture and handling with laboratory equipment. Figure 26 illustrates the construction details of the panels.

The demonstration panels were constructed of low-grade 4/4 lumber remaining from earlier siding experiments, and the 3/10-inch ponderosa pine veneer previously produced from the low-grade veneer logs. The rough lumber-core stock was equalized and conditioned in a dry kiln to 7-9 percent moisture content, a level considered necessary for the plywoodlike type of construction involved.

The conditioned material was ripped random width to remove open defects, face jointed, and surfaced to 25/32-inch thickness.

Only open defects were removed in ripping; all sound defects such as knots, stain, and pitch streaks were allowed to remain in the material, as were small open defects such as borer holes, splits, and torn grain. A representative indication of material recovery could not be obtained, since the lumber being used was largely scrap and short boards of odd lengths, but an estimated surface area loss of 10 percent was sustained in ripping out open defects. This figure is generally representative of the loss that would be sustained in a production process.

The edges of the material were neither jointed nor surfaced unless an open joint greater than 1/16 inch resulted from laying up rough stock. Slightly loose or relieved joints provided between core stock pieces by the rough-sawn edges were considered desirable. Slightly open joints may help relieve glue-line stress as the panel changes moisture content in use.

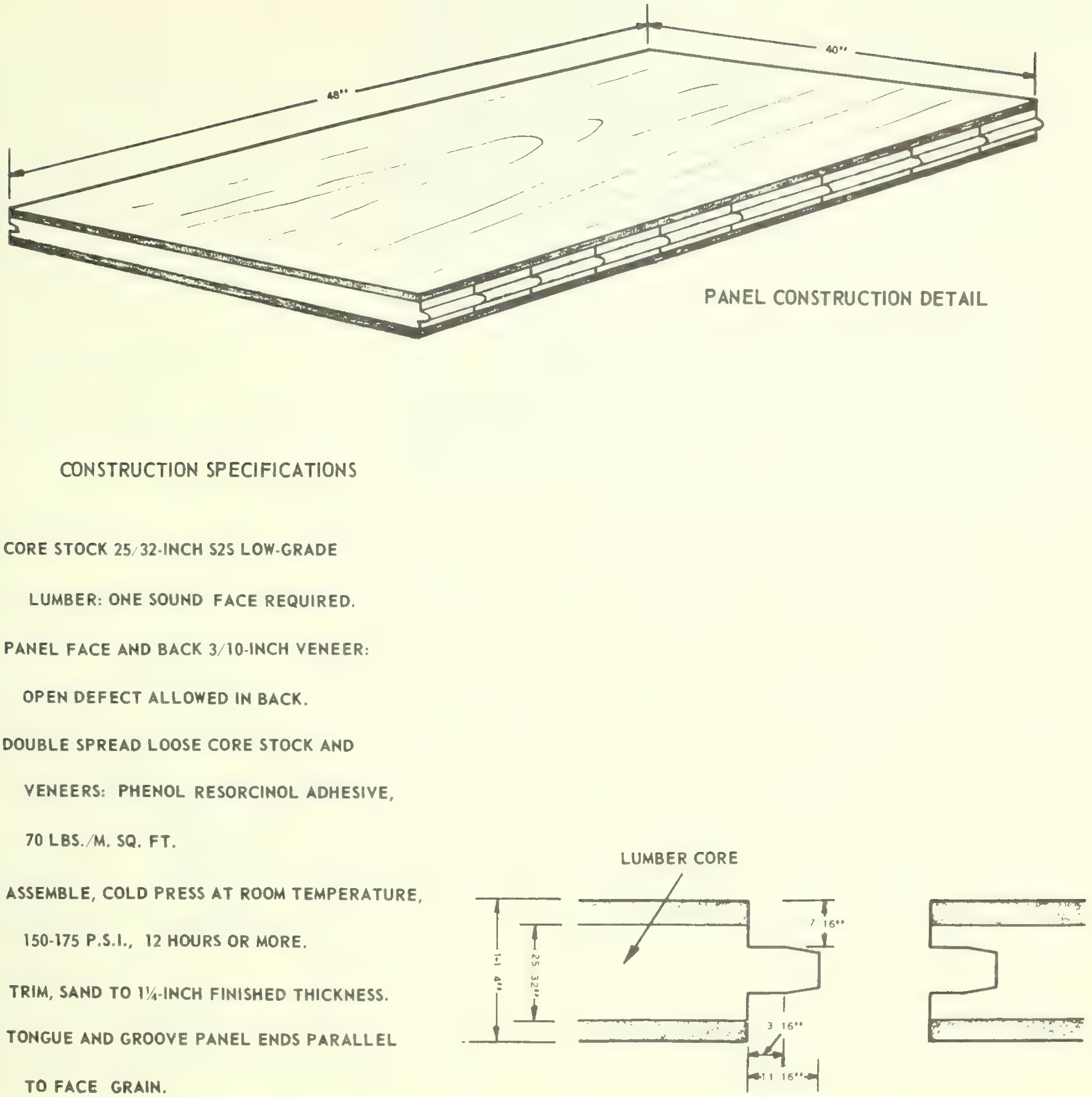
Face and back 3/10-inch veneer was sorted and clipped to rough panel dimensions. Panel faces were required to be free of open defects, except for splits or other small defects not exceeding 1/16 inch in width. Some face veneers with open defects were purposely included for subsequent patching tests with epoxy resin. Back veneer was allowed to contain open defects without restriction.

The panels were double spread with 70 pounds of a phenol-resorcinol adhesive per M square feet of glue line. The face and back veneer sheets were spread by hand roller while the core stock was passed through a conventional roller spreader. The laid-up panels were cold pressed at 150 pounds per square inch for a period of 12 hours or more (fig. 27).

The panels were then trimmed, and the few included open defects in face veneers were patched with an epoxy resin-wood flour patching compound. The panels were sanded by stages to determine the depth of sanding cut necessary to achieve a suitable face and thickness. The same amount was removed from both front and back veneers to retain a balanced construction. After removal of approximately 0.030 inch of material from each panel surface, the surfaces were judged suitable for the use intended. The finished panels measured 1.330 to 1.339 inches in thickness. On the basis of sanding allowance alone, a green veneer thickness of 0.275 inch rather than 0.300 inch appears adequate for production of a finished, touch-sanded, 1-1/4-inch panel.

The panels were sanded without difficulty, except that the high pitch content of the ponderosa pine plugged the closed-coat paper quickly. Again, this could be avoided through the use of open-coat paper and wide-belt sanders. Slight surface shelling visible on the face of some finished panels was attributed in part to repeated sanding necessitated by the partially plugged paper. The epoxy resin-wood flour patches used in several panel faces were sanded without difficulty and appeared to perform quite well.

The finished panels were end matched with the tongue-and-groove joint illustrated in



PANEL CONSTRUCTION DETAIL

CONSTRUCTION SPECIFICATIONS

(1) CORE STOCK 25/32-INCH S2S LOW-GRADE LUMBER: ONE SOUND FACE REQUIRED.
(2) PANEL FACE AND BACK 3/10-INCH VENEER: OPEN DEFECT ALLOWED IN BACK.
(3) DOUBLE SPREAD LOOSE CORE STOCK AND VENEERS: PHENOL RESORCINOL ADHESIVE, 70 LBS./M. SQ. FT.
(4) ASSEMBLE, COLD PRESS AT ROOM TEMPERATURE, 150-175 P.S.I., 12 HOURS OR MORE.
(5) TRIM, SAND TO 1¼-INCH FINISHED THICKNESS.
(6) TONGUE AND GROOVE PANEL ENDS PARALLEL TO FACE GRAIN.

TONGUE AND GROOVE DETAIL

Figure 27.--Manufacturing specifications developed for lumber core laminated flooring.

figure 26. This joint was designed to maintain flush surface alignment of the installed panels, and eliminate the need for blocking under panel end joints.

Lumber-core flooring tests and evaluation

Since the product was designed to be used in a load-bearing application, certain stiffness and strength properties were required for adequate performance. Stiffness and strength tests were performed on randomly selected panel sections 10-1/2 inches wide (fig. 28). Twelve such specimens were tested, with the results shown in table 15.

While the number of test specimens was insufficient for an extensive evaluation, the test results were rather constant. They indi-

Figure [illegible].--A [illegible] lumber-core flooring panel is placed in the cold press.

Table 15.--Physical characteristics of three-ply lumber-core flooring made of low-grade ponderosa pine

Specimen No.	Depth	Width	Length	Moisture content	Specific gravity	Modulus of rupture	Bending stiffness, based on deflections-- Midspan between supports	Bending stiffness, based on deflections-- Between load points (pure)
	Inches	Inches	Inches	Percent		Lbs./sq.in.	Lbs.-inches² per inch of width	Lbs.-inches² per inch of width
1-2	1.336	10.41	48.09	10.5	0.403	4,000	154,600	156,000
3-2	1.336	10.42	48.10	10.7	.406	2,850	155,800	169,000
3-3	1.335	10.42	48.10	10.8	.409	3,310	160,400	173,000
3-4	1.332	10.39	48.10	10.3	.412	2,350	139,000	137,200
6-3	1.335	10.41	48.08	10.5	.405	3,250	133,500	141,000
6-4	1.333	10.43	48.10	10.5	.399	2,400	146,000	162,000
7-2	1.337	10.41	48.09	10.3	.422	2,440	152,000	171,000
7-3	1.339	10.42	48.10	10.4	.418	3,160	150,000	162,500
8-2	1.338	10.42	48.07	10.9	.404	3,000	158,000	175,000
8-4	1.329	10.43	48.10	10.7	.398	5,220	170,500	181,400
10-2	1.339	10.40	45.00	10.1	.421	2,500	113,200	120,500
10-4	1.330	10.43	45.02	10.3	.411	3,110	120,200	126,000
Average	--	--	--	10.5	.409	3,130	146,100	156,200

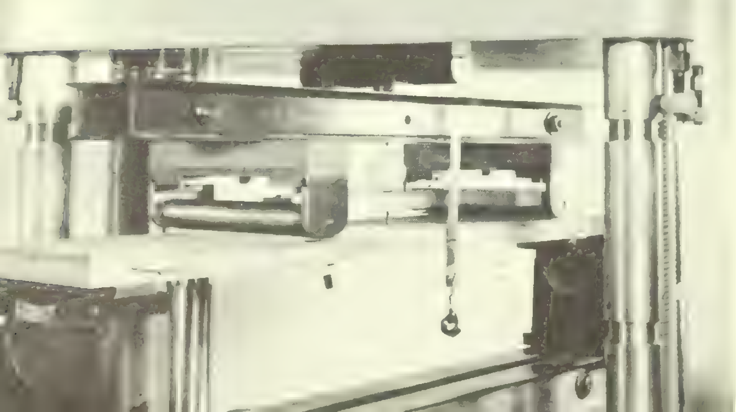


Figure 28.--A laminated lumber-core flooring panel positioned in a mechanical testing machine.

cate that both stiffness and strength are materially affected by the presence of knots and associated areas of short grain. The intergrown knots of ponderosa pine characteristically have associated with them large areas of irregular or short grain. All of the test specimens failed suddenly in the wood on the tension side, with no indication of gradual compression failure. Failure occurred in an area of short grain in each instance (fig. 29).

The test data indicate that the stiffness of the material is about 71 percent of that expected for the species, and modulus of rupture is about one-third of the average for the species. Furthermore, the brash tension failures indicate that the impact strength of the plywood would be quite low. As designed, the product is definitely unsuitable for the load-bearing uses intended. To be suitable, either redesign or stricter limitations upon allowable defect is necessary.

Redesign of the product was considered, on the basis of the strength and stiffness data developed in the tests. It was found that face plies 1/2 inch thick would be required to obtain the deflection characteristics of commercially available combination flooring products. An alternative design with acceptable deflection characteristics would require a 1-1/8-inch lumber core between 3/8-inch face veneers. Neither of these alternatives appears to be practically feasible. A more feasible alternative would be to reverse the 8-foot direction of the panel, so it would span two joist openings with the grain direction of the face veneers. This would require 8-foot face veneers, cut to the 3/10-inch thickness originally specified. The performance of the product used in this manner would still depend heavily upon the quality of face veneers used. It appears that any load-bearing application of the product will require stringent limitations upon allowable defect (especially knots) in the veneers used.

The basic concept of cross laminating thick veneers to lumber raises questions of dimensional stability, glue-line integrity, and face checking resulting from exposure to changing environmental conditions. To evaluate these factors, six 4-foot test specimens were cycled between 80 percent and 30 percent relative humidity conditions, at a temperature of 80° F. Moisture content, glue-line integrity, face checking, bow, and dimensional change were recorded after exposure for 4 months to each set of conditions.

Panels in equilibrium at 80 percent relative humidity rose from 7 percent to 13.5 percent moisture content. No delamination or face checking occurred. The panels exhibited an average bow of 0.02 inch, and maximum of 0.04 inch, over a 42-inch span. The panels did, however, develop a slight waviness associated with the grain of the core stock. The waviness was sufficient to cause misalignment of the tongue and groove on unjointed panels. As a result, a longer, more tapered tongue was incorporated in the design (see fig. 26).

The panels increased 1.9 percent in thickness and 0.12 percent in length, under 80 percent relative humidity conditions. The 0.12

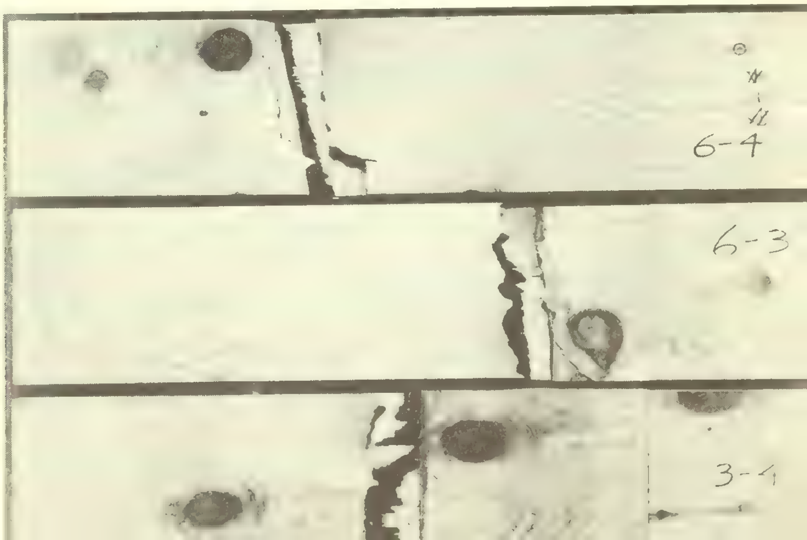


Figure 29.--These laminated flooring test specimens show tension failure in areas of short grain.

percent increase in length would result in an increase of about 1/16 inch over a 4-foot span, well within acceptable limits.

The same panels in equilibrium at 30 percent relative humidity dropped to 6 percent moisture content. No delamination occurred. An average of six small checks, none exceeding 1/32 inch in width, formed on the panel faces. Checks of this size are quite acceptable. Bow dropped to a maximum of 0.025 inch over a 42-inch span. Waviness and associated tongue and groove distortion disappeared, for all practical purposes. Panel thickness and length returned to within 0.1 percent of original dimensions.

The single significant limitation indicated by the tests was the tendency of panels to develop short waves at high humidity. Limiting the width of core stock to a maximum of perhaps 6 inches should reduce this tendency to allowable limits.

The design concept used in developing this product appears to be entirely valid. With the exception of the strength and stiffness deficiencies induced by the quality of material used, the product appears to perform satisfactorily. As previously pointed out, strength and stiffness deficiencies seriously curtail the use of the product in load-bearing applications. Potential uses for the product will depend heavily upon the quality of face veneers available for use.

Flex-floor finished flooring

The finished flooring product previously described, Flex-floor, is especially adapted to laying over concrete floors, although it can be laid over any type of subfloor. Its adaptability to concrete subfloors should prove particularly attractive in concrete slab-type construction.

A sufficient quantity of Flex-floor was manufactured to demonstrate the possibility of using low-grade ponderosa pine lumber as backing material. Chestnut oak flitches were sliced to provide face veneer for the Flex-floor. The veneer was sliced 1/7 inch thick to provide allowance for drying shrinkage, press compression, and sanding. In addition, some rotary-cut birch veneer was used on a portion of the flooring. Trimmings from the grade 3, 4, and 5 common ponderosa pine lumber provided for overlaying were used for backing material.

The rough 4/4 backing stock was placed in a dry kiln for equalizing and conditioning to 7-9 percent moisture content, then ripped to remove open defects, face and edge jointed, and surfaced to 5/8-inch thickness. All sound defects were allowed to remain in the stock as were slight open defects, such as splits, borer holes, and torn grain.

Since the material being used was principally small stock of odd dimensions, a representative volume recovery determination could not be obtained. Less than 10 percent of the initial surface area was lost in ripping out open defects, however.

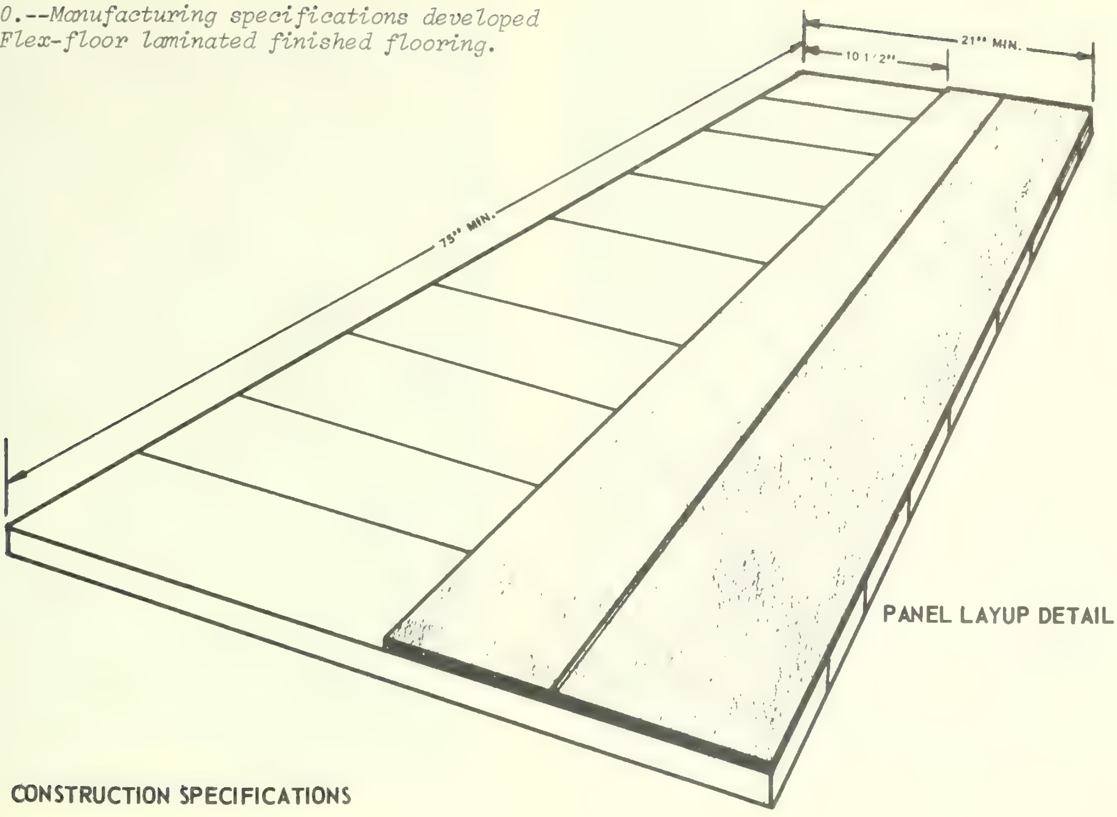
The base stock was laid up in rough panels 21 by 75 inches (fig. 30), which yielded two 9- by 72-inch units of finished flooring.

The double-width panels were bonded with an acid-catalyzed phenol-resin adhesive, with a single spread of 55-60 pounds per M square feet of glue line. The base stock was laid out loose on a metal caul, and one edge was aligned with a straightedge. The adhesive was applied to the face veneer by hand roller, and the veneer was placed on the loose panel of base stock (fig. 31). The laid-up panels were cold pressed at a pressure of 150-175 pounds per square inch for 12 or more hours.

After removal from the press, the cured panels were face sanded lightly to provide a suitable surface for finishing, then ripped down the center line to form two single units of flooring. The flooring was trimmed and edge jointed, then end and edge matched with standard 1/4-inch tongue and groove, which left a finished face dimension of 9 by 72 inches.

The flooring face veneer was V-grooved in a random-width pattern to simulate random-width planking. The groove pattern was positioned on the flooring so that a V-groove coincided with each edge glue line, to provide

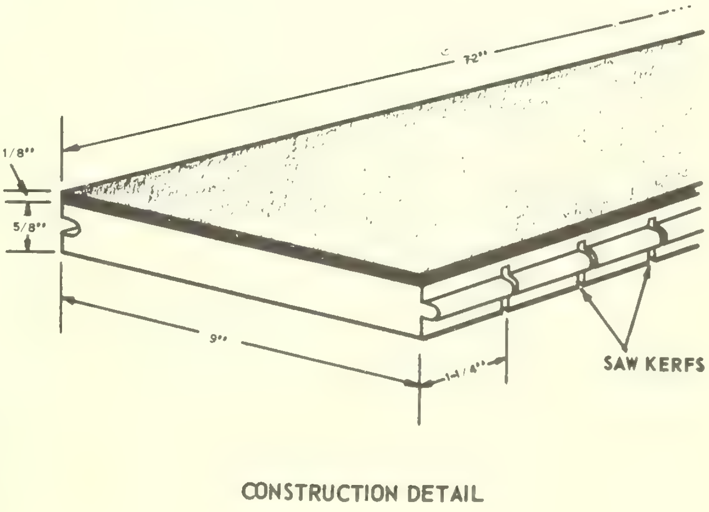
Figure 30.--Manufacturing specifications developed for Flex-floor laminated finished flooring.



PANEL LAYUP DETAIL

CONSTRUCTION SPECIFICATIONS

(1) LOW-GRADE S4S 5/8-INCH BASE STOCK LAID UP LOOSE IN 21-INCH BY 75-INCH PANELS.
(2) HARDWOOD 1/7-INCH FACE VENEER SINGLE SPREAD WITH PHENOL RESIN ADHESIVE, 55-60 LBS./M. SQ.FT.
(3) ASSEMBLE, COLD PRESS AT ROOM TEMPERATURE, 150-175 P.S.I., 12 HOURS OR MORE.
(4) FINISH SAND FACE VENEER, RIP PANELS DOWN CENTER, TRIM, EDGE-JOINT FLOORING WIDTHS.
(5) END- AND EDGE- MATCH WITH TONGUE AND GROOVE.
(6) SAW KERF BASE MATERIAL AT 1¼-INCH INTERVALS.
(7) CHAMFER FACE EDGES AND ENDS, AND VEE-GROOVE FACE VENEER AS DESIRED.
(8) PREFINISH AS DESIRED.



CONSTRUCTION DETAIL

a logical break between grain patterns. Remaining V-grooves were allowed to fall at random in single veneer strips.

The base stock was grooved with 1/8-inch saw kerfs on 1-1/4-inch centers across the direction of face veneer grain (see fig. 30).

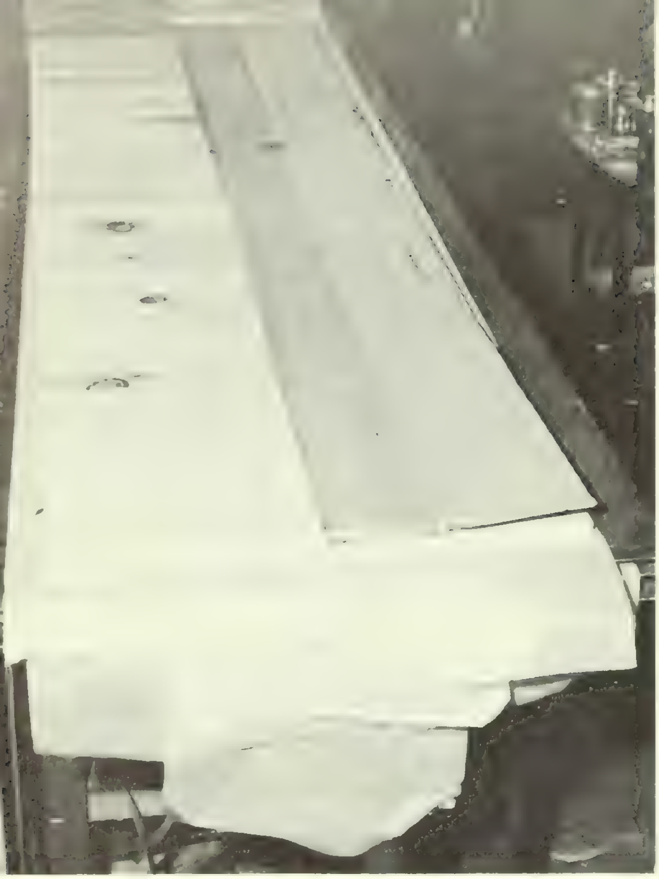


Figure 31.--Base stock for Flex-floor was laid up in double flooring widths; hardwood face veneer was then spread with adhesive and applied to the base stock.

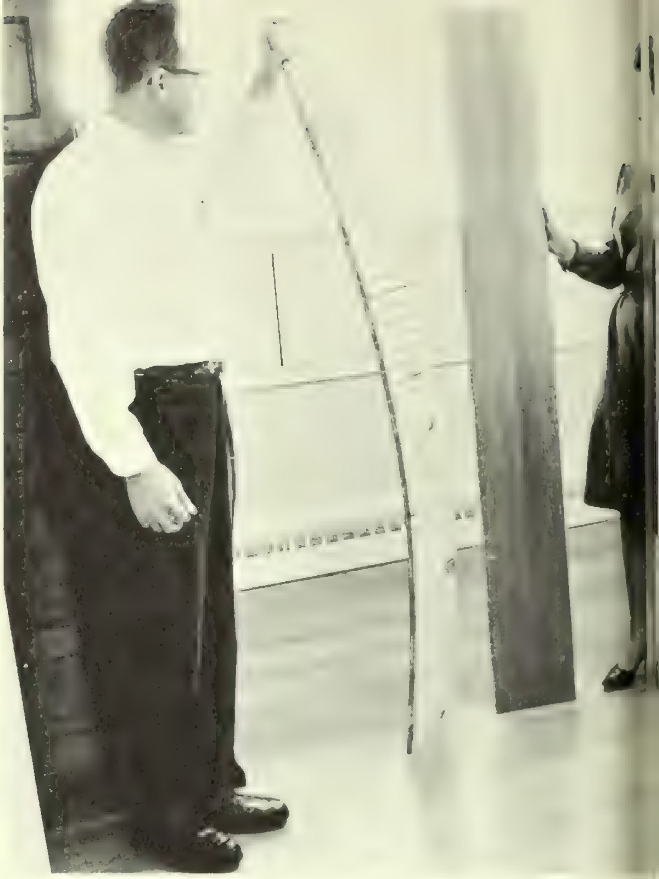


Figure 32.--Flex-floor laid over a standard plywood subfloor. The reversed section of flooring shows the flexibility of the kerfed low-grade ponderosa pine base stock.

The kerfs were cut 9/16 inch deep, to within 1/16 inch of the face veneer.

The completed flooring was prefinished by filling, sealing, and waxing (fig. 32). Since the flooring is of uniform thickness, edge and end matched, and in large pieces, it can be prefinished without difficulty.

Flex-floor can be produced in a wide variety of sizes and styles, with a minimum of production detail. Its production can be readily integrated with other cut stock and laminating processes such as overlaid product manufacture. For production of Flex-floor in the Southwest, hardwood face veneers would have to be ''imported''; this is common practice in the plywood industry, however.

PLANT EQUIPMENT AND CAPITAL INVESTMENT REQUIREMENTS

The plant equipment and investment required to manufacture a product in economically practical quantities depends a great deal upon the ''minimum economic size'' of operation for the particular industry. Generally, the minimum economic size of operation is not fixed, but varies with the production process, production and marketing conditions, and external cost factors. Qualifying assumptions are necessary. There is a wide range of operating modes and equipment for any production operation. Most items of heavy equipment are available in a variety of sizes, styles, and capacities. Some manufacturing processes, such as sawmilling, are accomplished with rather uniform standardized items and groupings of equipment. Even in such standardized processes, however, a wide range of automation and equipment capacity is available that materially affects capital investment.

To determine the equipment and investment needed for a plant, it is necessary to establish an operational design technically and economically suited to local conditions. The investment needed to establish an operation varies with:

1. Size and quality of raw material.
2. Degree of integration with existing industries or processes.
3. Local availability of power and labor.
4. Effect of labor costs upon degree of automation desired.
5. Relative location with respect to raw material and markets.

Equipment and investment estimates can furnish only broad guidelines, subject to wide variation. For any given type of product, however, there exists a minimum economic size of operation dictated by the nature of the process and the minimal equipment required to produce at all. Most manufacturing industries recognize such a minimum plant size. This minimum size tends to become larger as the industry grows and the process becomes more intricate and refined. It is with such a ''minimum economic size'' in mind that the following equipment requirements and investment costs are presented.

For items of equipment that are relatively standardized, an average installed cost is shown. Some items of equipment, however, are available in such a wide range of varieties and sizes that an ''average'' cost becomes meaningless. For such equipment, no cost is shown. It must be emphasized that the plant equipment costs presented are averages, are based upon the minimum economic size of efficient plant generally recognized by industry, and are subject to frequent change.

Veneer and Plywood

The following equipment requirements are considered minimum for a softwood plywood plant that utilizes 4-foot veneer bolts to produce approximately 25 million square feet (3/8-inch standard) per year for a specialized product such as underlayment, in a 4-foot by 4-foot panel size:

Plant equipment, softwood plywood,
4-foot by 4-foot panel

Quantity	Equipment	Installed cost
--	Block and log handling	$ 25,000
3	Heating vats	20,000
--	Block handling to lathe	5,000
1	Lathe, 54 inches	40,000
1	AC-DC lathe drive	12,000
--	Veneer conveyor system and grading table	25,000
2	Automatic green clipper, 54 inches	14,000
1	Scrap conveyor from lathe	6,000
1	Automatic knife grinder, 54 inches	6,000
1	Roller conveyor veneer dryer	120,000
1	Automatic moisture detection system	6,000
1	Dryer unloader conveyor	5,000
1	Dry sizing clipper, 54 inches	2,000
1	Patch blanking saw	2,000
1	Veneer patcher with gravity rolls	13,000
1	Patcher scissors lift	1,000
1	Veneer jointer, 54 inches	8,000
1	Tapeless veneer splicer	6,000
1	Glue mixer	3,000
1	Hot plate press, multiple opening, 4' x 4'	60,000
1	Wide belt sander	25,000
1	Hydraulic elevator at hot plate press	6,000
2	Fork lift trucks	18,000
1	Glue storage tank	11,000
--	Misc. hand trucks, pellets	1,000
--	Building with 60,000 sq. ft. of floor space, equipped with sprinkling system, lighting, concrete floor and machine foundations, electrical wiring, and steam piping to vats and press	--

Plant equipment, softwood plywood, 4-foot by 4-foot panel

Quantity	Optional equipment	Installed cost
1	Automatic block-centering device and lathe charger	20,000
1	Core conveyor from lathe	5,000
1	Scrap conveyor from clipper	8,000
1	Wet veneer chipper	24,000
1	Core chipper	16,000
1	Blow system, chippers to car	16,000
1	Dryer feeder	24,000
1	Dryer unloader	14,000
1	Hot press load trim band saw	1,000
1	Air compressor and tank	8,000

A plant of this size would probably prove too small for production of standard products such as sheathing, in a highly competitive market. Most of the softwood plywood plants recently constructed to produce such standard products have been designed for annual output capacities 3 to 4 times greater than this, and have entailed investment costs of from 2 to 10 million dollars.

The optional equipment listed is considered desirable as an addition to the minimal equipment. Its use could materially reduce labor costs, and more fully realize the capacity potential of the basic equipment.

Laminated Beams

If vertical lamination of low-grade lumber to produce construction beams can be integrated with an existing sawmill operation, the amount of equipment initially required will be materially reduced.

In defining minimum equipment requirements for a laminating operation, it was assumed that an existing kiln would be used to reduce the moisture content of the material to 8-10 percent. It was also assumed that the material would be surfaced on two sides with existing planer facilities, and would not be surfaced again prior to laminating. Tests indicate this would be feasible. The beams are designed to be constructed of full-length laminations; therefore, scarf-joint and finger-joint equipment is not essential, although it might be advantageous.

The suggested minimum economic size plant should be able to process 4,800 board feet of material per 8-hour day. The equipment considered necessary for this size of operation is listed in the following tabulation:

Plant equipment, beam lamination

Quantity	Equipment	Installed cost
1	Glue spreader, 18 inches	$ 1,600
200 ft.	Roller bed, 14 inches	500
200 ft.	Screw clamps and carrier run	5,000
1	Compressor and tank	1,000
2	Pneumatic wrenches	500
1	Glue mixer	500
200 ft.	Jigs to retain output under pressure, 4 sq. ft. cross section	4,000
1	Overhead block and tackle, overhead rail	5,500
1	Cabinet surfacer or heavy duty jointer	6,000
--	Hand sanders, drills, saws	800
--	Misc. brushes, benches, tables, tools, equipment	1,400
--	Building with 10,000 sq. ft. of floor area, concrete floor	--

In addition, if the beams are subjected to nondestructive stiffness testing, the cost of installing and using such equipment must be considered. An end coating such as paraffin should be applied to the ends of beams prior to shipment; however, for limited production such end coatings can be applied effectively by hand.

The equipment indicated above is in general specifically adapted to laminated beam production. Greater production versatility could be achieved, however, by using some less specialized equipment with a wider range of product capabilities. The following section is concerned with equipment suited to a variety of cold press and laminated products, and indicates how beam production can be integrated with the production of other products.

Cold Press Overlaying and Laminates

The production of cut stock, end-and-edge glued overlaid products, or laminated flooring products can be integrated quite effectively with a sawmill operation. A wider range of end products provides the means for utilizing varying qualities of material, which can in turn lead to reduced unit costs in overhead, logging, and service functions. A single sales organization can also effectively develop sales of products closely related in end use.

The basic items of equipment used in producing many secondary mill products are highly versatile and applicable to the production of a wide range of products. For example, cut stock, end-and-edge glued overlaid products, laminated flooring products, and small laminated beams can be produced with minor variations of the same basic equipment. This provides a high degree of production versatility, an important feature in patterning production to meet changing market demands.

In view of the interrelated equipment requirements, the production of overlaid siding products and laminated flooring products can be considered as a single enterprise. Furthermore, the equipment involved also provides some capability to produce laminated beams. Mixed production or frequent production changes from one type of product to another would probably prove impractical since different adhesives, spreader roll configurations, and equipment preparations are involved. A basic capability to change from one type of product to another, in response to market changes or other criteria, however, is invaluable. The basic production line and equipment can be converted from one product to another relatively quickly and inexpensively.

In considering the minimal equipment necessary to produce overlaid and laminated products, preference was given to versatile types of equipment. The equipment required to produce overlaid siding products and laminated flooring products is listed in table 16. Laminated beams, covered separately in the previous section, are again included here, since the basic equipment also provides some capability for their production. The range of versatility associated with each item of equipment is indicated.

In addition to the equipment listed, handling and packaging equipment not already available must be considered.

The inherent versatility of the equipment can be further enhanced by a plant layout that minimizes rearrangement for specific products. Figure 33 presents in schematic form a production flow system designed to utilize the equipment listed, and facilitate production of any of the products considered.

Particle Board

Low-quality ponderosa pine material can be used in the production of particle board. The test boards had highly satisfactory dimensional stability and strength characteristics. Boards of either conventional or special construction appear worthy of consideration.

Commercial particle boards are currently produced by a rather large number of firms, however, and competition in the open market is keen. The captive particle board operation, in which the board is used in the manufacture of a finished product, provides a potential exception. Any contemplated particle board operation should be preceded by, and based upon, a careful survey and analysis of marketing potential.

Particle board products can be produced through several dissimilar processes. The primary commercial processes for making particle board are (1) multi-platen press, (2) vertical extrusion press, and (3) horizontal extrusion press. The equipment necessary for production differs widely between processes; in addition, equipment suitable for any single process is subject to wide variation. Consequently, no attempt is made to present detailed minimal equipment and capital investment requirements for particle board production.

Several generalized "rules of thumb" for minimum economic size of operation, and associated capital investment, have developed. A commonly suggested minimum level of production for a multi-platen flat press installation is 40 tons of dry material per day, or approximately 26,000 square feet of board

Table 16.--Plant equipment, overlaying and laminating

Quantity	Equipment	Installed cost	Combination siding-sheathing	Resawn beveled siding	Flex-floor	Laminated--	
						Lumber core flooring	Beams
		Dollars					
1	Straight line rip saw	5,000	x	x	x	x	
--	Rip and crosscut power feed cut-up saw	3,000	x	x	x	x	
--	Finger-jointing equipment (tongue and groove optional)	--	x	x			
--	End and edge gluing equipment	--	x	x			
--	Plugging equipment, 3-inch capacity (optional)	1,000	x	x	x	x	
1	Single or double surfacer, 52 inches	10,000	x	x	x	x	x
1	Roller coater, 52 inches	2,000	x	x			
1	Glue spreader, 52 inches	3,000	x	x	x	x	x
1	Cold press, side loading, 42-inch opening, 50 by 150 inches, compressed air or hydraulic actuation	10,000	x	x	x	x	
--	Press I-beams, cauls, equipment	2,000	x	x	x	x	
--	Rip and crosscut trim saws, table (finished end)	3,000	x	x	x	x	x
1	Double spindle shaper with power feed (single end tenoner, optional)	6,000	x	x	x	x	
--	Preservative dipping troughs and conveyor system	1,000	x	x			
1	Belt sander	6,000			x	x	
--	Building with 20,000 square feet of floor area, concrete floor	--	x	x	x	x	x
Additional equipment required for specific products:							
1	Vertical band resaw, adjustable tilt	10,000		x			
1	Face groover, simulated planking	1,000			x		
1	Gang saw, power feed (kerfing base stock)	5,000			x		
--	Face veneer finishing equipment	2,000			x		
1	Veneer jointer, manual feed[1]	5,000			x		
1	Veneer edge-gluer[1]	10,000			x		
--	Beam clamps and clamp carrier	5,000					x
1	Jointer, power feed	3,000					x

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[1] Veneer jointing and edge-gluing equipment will be unnecessary if hardwood face veneers for Flex-floor are purchased pre-sized.

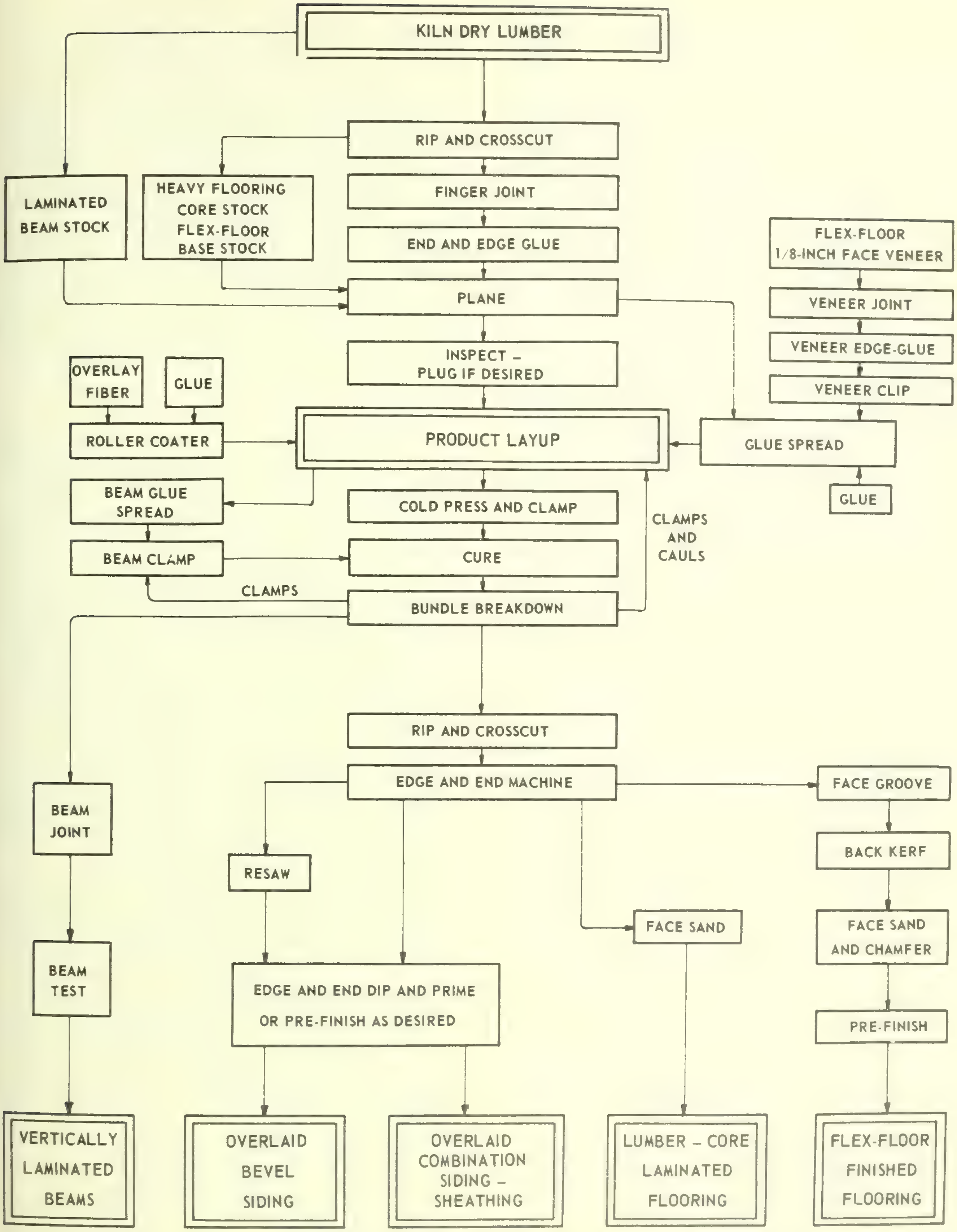

Figure 33.--A basic production flow design for the manufacture of both overlaid and laminated products. Designed by Bruce G. Heebink, Engineer, Forest Products Laboratory.

per day (3/4-inch basis). The capital investment for such a plant has been estimated to involve $20,000 to $25,000 per ton-day of capacity, or about 1 million dollars minimum. Extrusion-process plants, which can generally operate economically on a somewhat smaller scale and involve less capital investment per ton of capacity, would perhaps entail a capital investment of one-third to one-half this amount. Again, these values are broad estimates, and are subject to considerable variation under differing circumstances.

Investment requirement alone should not be the sole criteria for comparing flat-press and extrusion processes. The products of the two processes differ considerably. For most uses, extruded boards have poorer physical characteristics than flat-pressed boards. In addition, flat-press processes provide more latitude for engineering boards to particular specifications, such as multi-layer boards. Flat-pressed particle boards make up the bulk of current production.

FURTHER UTILIZATION POTENTIAL

The current study has by no means exhausted the range of possible new uses for low-grade ponderosa pine in either log, lumber, or residue form. The products specifically considered were chosen for their apparent adaptability to the immediate problem, plus professed industry interest in them. Generally speaking, they represent either means of avoiding production of low common grade lumber, or means of effectively using it after it is produced. Only incidental attention was given the utilization of sawmill residue materials, a prime factor in realizing better utilization of the resource.

An account of utilization potential for low-grade ponderosa pine timber would not be complete without mention of some of the additional utilization possibilities for the species:

1. The fabrication of selected wood products for local markets.
2. Means of utilizing mill residues currently wasted.
3. Fiber-board production in conjunction with current pulp operations.
4. Chemical conversion.

Wood Product Fabrication

The fabrication of wood products for local markets offers unique advantages for sawmills of practically any size. For many rough wood products such as boxes, bins, pallets, and snow fence, very little additional equipment and capital investment are required. Most such products can effectively utilize the lower grades of common lumber. In addition, secondary manufacturing or processing beyond the lumber stage adds appreciably to the labor force sustained and the total product value achieved, which augments area or community well being.

In the Southwest, a potential market exists for agricultural bins and boxes, and industrial pallets. The citrus fruit and truck-garden industry in the Southwest uses paperboard and plastic final packaging, but depends extensively upon wooden bins and crates for picking, handling, and processing. Bin pallets (combination bin and pallet) are commonly used in citrus groves as containers for transporting, storing, and processing fruit. Bin pallets are normally rather heavily constructed, and designed for a life expectancy of several seasons. Acceptable agricultural bin pallets can be constructed from low-quality material, through selective cutting and selection of component parts. Smaller wooden boxes and crates are also widely used in the fruit and truck-garden industry.

Practically all manufacturing and distribution industries handle materials and products with forklifts, and most have developed a "palletized" system of material storage and transfer. Because pallets can be produced from the lower common grades of lumber and require little specialized equipment or skills, their production is easily adapted to either manual or automated assembly.

Other manufactured products that can easily be integrated with sawmill operations include fence lath, wire-bound snow or ornamental fence, surveyor's stakes, and industrial crating. The manufacture of such products may be particularly attractive to smaller operations, since very little additional capital investment is required.

Residue Utilization

Much of the residue from lumbering operations in the Southwest is not currently utilized. The marked improvement brought about by the establishment of a local market for pulp chips is still insufficient to absorb a high proportion of the total available supply. A number of products (other than the particle boards previously discussed) provide potential outlets for residue: charcoal, briquetted fuel, natural wood fuel, soil conditioning and mulching materials, and such specialty products as barn and feed-lot bedding, wood flour, and sweeping compound.

The market for charcoal has gained strength in recent years, due primarily to increased interest in outdoor cookery. This is particularly true in areas such as the Southwest with moderate year-round weather. The development of continuous carbonization retort methods of charcoal production make feasible the use of hogged residue and miscellaneous wood fines. Bark can be included with other wood material if it is reduced to comparable size before processing. Since continuous retort processes produce fine charcoal, briquetting is necessary. Briquetted charcoal is somewhat favored over lump charcoal by both dealers and consumers, however, and would enjoy some market advantage. Although the capital investment in continuous carbonization and briquetting equipment is substantial, a cooperative development among a number of mills might be considered. The recently developed gas recycle retorts operating on either short-length round or slab wood provide an additional important means of efficient production.

High-density briquetted fuel, produced from sawdust and wood or bark fines, also presents residue utilization potential. Ponderosa pine has proven to be a preferred species for wood briquets from sawdust or other fine material. Wood particles are self bonding when briquetted under high pressure at elevated temperatures, and thus require no added binder. High-quality briquets can also be produced from bark alone. To develop necessary strength and hardness in wood briquets, current practices require that the material be quite dry, preferably from 6 to 10 percent moisture content. Various types of high-temperature driers or short-cycle flash driers will reduce the moisture content of waste material. Several wood-briquetting plants in the United States use high-pressure molding machines to produce pressed logs suitable for fireplace and similar use. In addition, there are a number of extrusion-type briquetting machines in operation that produce pellets or stoker-size briquets.

Sawdust, shavings, and hogged wood or bark have received attention as soil conditioning and mulching materials. These materials have essentially no fertilizer value unless they are composted. When added to the soil, however, they do increase moisture retention, induce better aeration and tilth, and supplement native humus. When used as a mulch, wood materials reduce evaporation, retard erosion, and aid in weed control.

Untreated raw-wood residues used as mulches or conditioners will compete for available nitrogen in the soil as they decompose, and can create a nitrogen deficiency. Consequently, most commercially prepared soil additives from wood are either composted or chemically treated to add nitrogen. Bark or sawdust may be composted with corral or feed-lot manure to satisfy the nitrogen requirement. Aqueous ammonia and micro-organism inoculants are also sometimes added, and greatly speed composting. Ponderosa pine bark seems particularly well suited to this use, since it hammer-mills more uniformly than do fibrous barks.

In areas in which feedlots and livestock enterprises are common, wood chips and shavings may be salable as bedding material. Commercial shaving balers simplify packaging, storing, and handling the material. A residual benefit may be derived from the natural composting of the material while in use as bedding.

Other potential uses for selected mill residue and sawdust include such products as wood flour and sweeping compound. Ponderosa pine residue appears to be well suited to the production of wood flour, since it is not strongly acid, is light in color, and relatively free from excessive pitch. Although the market for wood flour is rather small, demand is probably increasing in newer industrial areas such as the West Coast. Wood flour, consisting of finely divided wood particles about the size of cereal flours, is used as a filler in linoleum, explosives, and plastics. It is also used to produce molded wood products, and as a cleansing agent, a mild abrasive, and a filler in some flues and cements. Wood flour may be reclaimed from sander dust or sawdust, or may be manufactured. A variety of wood-flour mills are in use, including attrition mills for sawdust-size material and hammer mills or crushing mills for larger residues. Oversize particles are air separated or mechanically screened from the flour. The specifications for wood flour are rather exacting for most uses, and require close quality control.

Sawdust is commonly used as an absorbent in floor sweeping compounds, which are usually composed of sawdust, clean sand, salt, and oil or water-wax emulsion. Oils are used in compounds designed for cement, terrazzo, or wood floors, while wax emulsion is used in compounds for linoleum, rubber, and asphalt floors. In addition, dyes and scented oils are often added. Sweeping compound can easily be mixed in a revolving drum or concrete mixer, and discharged directly into marketing containers.

Fiberboard Products

The production of fiberboard or hardboard products can utilize extensive quantities of low-quality material in log or residue form. Since the initial processing of raw material can be essentially that used in producing groundwood pulp, fiberboard production could be integrated with existing groundwood pulp operations. Fiberboard production has been highly developed, however, and competition in the open market is intense. Fiberboard product potential will depend heavily upon the strengthening of established markets and development of new markets.

Fiberboard production requires pulping equipment, Fourdrinier-type forming machines, multi-platen hot presses, and continuous driers, most of which are designed for high-capacity production. Consequently, minimal capital investment is high and large-capacity installations are common. It has been estimated that a plant designed around one multi-platen press (4-foot by 16-foot, 20-opening) must have available at least 90 tons of raw material per day.

Raw material for fiberboard is pulped by mechanical grinding, steaming, chemical pulping, or defibrating. Mechanical grinding is the most common method employed in producing insulating board. Most hardboard is produced by pulping wood in chip form. In conventional or wet-felting processing, the washed fibers are suspended in a slurry and deposited on a Fourdrinier wire or special forming machine. Hardboard is produced by hot pressing and drying the fiber mat. Insulation board is produced by drying the mat in a continuous dryer, without further hot pressing. Medium-density building board is produced by adding a binder to the fiber mat and hot pressing to a relatively low density.

In a process variation known as air-felting the fibers are partially dried, conveyed in air suspension, and formed into mats for hot pressing. A resin binder is added in the dry process.

For each step in fiberboard production there is a wide variety of techniques and equipment available. The processes present definite possibilities for improvement through innovation. New methods of raw material preparation, new handling methods, and new production techniques could easily improve the existing production cost structure.

Chemical Conversion

Research on the chemical conversion of wood and bark residues indicates that such conversion (although still largely in the development stage) is of potential importance. Several notable examples of successful chemical wood product operations do exist, however. These include the rayon industry, the charcoal industry, the naval stores and tall-oil industry, and the use of wood-derived chemicals in plastics and photographic films. Bark extractives currently yield phenolic derivatives useful as waterproof adhesive components, and tannins valuable as deflocculants in drilling muds.

Processes that may be useful in the economic recovery of industrial chemicals include fermentation, hydrolysis, and hydrogenation. Hydrolysis of wood will convert the hemicellulose and cellulose fractions to sugars, notably xylose and glucose. Wood sugars can be converted into a host of chemical products, including molasses and yeast. Xylose can be converted to furfural, a chemical used in the production of nylon. Glucose can similarly be converted to levulinic acid and other compounds potentially valuable as industrial chemicals. Other ways in which glucose can undergo further chemical conversion include fermentation to ethyl alcohol, microbiological conversion to food yeasts or glycerol, and hydrogenation to obtain glycerol and other polyhydric alcohols.

Wood hydrolysis has been used to produce sugars that have been concentrated to yield wood-sugar molasses on a pilot-plant basis. Wood-sugar molasses is potentially valuable as an animal feed. The feeding tests conducted indicated that wood-sugar molasses was the equivalent of black-strap molasses as a carbohydrate feed supplement. Minor adverse characteristics, such as a tendency for solids to form in the molasses during storage, can be corrected by modification of the production methods employed. Successful production of wood sugars depends more upon economic than technical considerations.

The growing trend toward integrated utilization of wood resources favors continued development of a chemical conversion industry. Chemical conversion can provide the last step in an integrated operation by utilizing material that is unsuited to other more demanding uses.

APPENDIX A

Ponderosa Pine Test Materials

Test materials for the study were selected from the lower grades of logs and lumber found in Arizona and New Mexico sawmills. Table 17 indicates the quantity and grade of test lumber provided. The test logs and special test materials are described below:

Item	Quantity	Description
Grade 5 sawlogs for peeling	4	10 ft.,13-21 inches diameter, 540 b.f.Scrib. Dec. C, typical grade 5 logs.
Grade 6 sawlog for chipping	1	12 ft., 18 inches diameter, 160 b.f. Scrib. Dec. C, typical grade 6 log.
Planer shavings	300 lbs.	Lower head, 1/16-3/32 inch cut; head angle, 63°; knife rake angle, 15°-20°. Knife cuts per inch, 16 at 180 f.p.m.; 9 at 325 f.p.m.
Debarked slabs	500 lbs.	--

Table 17. --Ponderosa pine test lumber

Width (Inches)	Length	Grade 3	Grade 4	Grade 5
	Feet	- - Board feet - -		
4/4 Common, rough:				
12	12	96	120	108
10	12	125	106	87
8	12	96	104	112
6	12	42	36	42
4	12	40	36	44
Total		399	402	393
4/4 Common, S2S:				
10	16	253	266	239
6/4 Common, rough:[1]				
12	12	90	72	90
10	12	72	72	72
8	12	60	60	60
Total		222	204	222

[1] 6/4 Common lumber substituted for 5/4 Common originally specified.

The saw logs designated for peeling were converted to eight 52-inch test bolts, for veneer and plywood production and test purposes. Each of the eight bolts was diagramed before peeling. Table 18 provides a description of each of the test bolts.

Table 18. --Veneer test bolt description

Bolt No.[1]	Diameter		Pith eccentricity[2]		Knots		Other characteristics
	Small end	Large end	Small end	Large end	Number	Size range	
	- - - Inches - - -					Inches	
2-2	19½	20½	1½	2	6	2 to 10	Spiral grain evident; few encased knots; intergrown bark pocket.
3-1	13½	14½	1½	1½	6	½ to 4	Compression wood evident in sapwood in one-quarter of bolt; some encased knots.
4-1	17½	18	0	¾	12	½ to 3	Heart rot evident in center of bolt; some encased knots.
5-1	21	21¾	1	1	7	¾ to 3½	Some intergrown bark; several encased knots.
2-1	20¼	22	2	2½	11	2 to 6½	Most knots intergrown; few encased.
3-2	13¼	13½	1½	1½	5	1 to 2	Compression wood evident in sapwood in one-quarter of bolt; some encased knots.
4-2	17½	18	½	1	12	1 to 4	Heart rot evident in center of bolt; some encased knots.
5-2	21	21	1¼	1¾	4	¾ to 3	Knots grouped--two-thirds of bolt surface clear; some encased knots.

[1] Bolts 2-2, 3-1, 4-1, and 5-1 were designated for production of 1/7-inch veneer; the remaining four bolts were designated for 3/10-inch veneer.

[2] In rotary cutting, all bolts were chucked in their geometric center.

APPENDIX B

Glossary

The terms employed in this publication are in general well known to one or more sectors of the wood utilization industry. Some terms, however, may be unfamiliar to those acquainted primarily with lumbering and associated activities. Terms that may warrant general definition, or specific definition regarding their particular use in this publication, are included in this section.

Board - an item of lumber less than 2 inches in nominal thickness.
  a. 4/4 lumber - lumber with a nominal thickness of 1 inch, and finished thickness of 25/32 inch.
  b. 5/4 lumber - lumber with a nominal thickness of 1-1/4 inches, and finished thickness of 1-5/32 inches.
  c. 6/4 lumber - lumber with a nominal thickness of 1-1/2 inches, and finished thickness of 1-13/32 inches.

Bow - distortion of a board characterized by deviation from flatness lengthwise.

Brashness - a condition in wood that causes it to break suddenly and completely across the grain when bent slightly.

Casehardening - a condition of stress in wood in which the outer fibers are under compressive stress and the inner fibers are under tensile stress.

Check - a lengthwise separation of wood, usually extending across the rings of annual growth; e.g., checks may extend radially from the pith or center of a log.

Compression failure - localized buckling of fibers produced by compression of wood along the grain beyond its proportional limit.

Compression wood - abnormal wood formed on the lower side of branches and inclined trunks of softwood trees; characterized by relatively wide, eccentric growth rings and excessive longitudinal shrinkage.

Conditioning treatment - a controlled high-temperature, high-relative-humidity kiln condition applied to bring about a uniform moisture distribution in lumber and relieve drying stresses.

Crook - distortion in which the edges of a board deviate from a straight line end to end.

Crossbanding - the inner plies of plywood that are oriented perpendicular to the face veneer; usually consists of narrower pieces of veneer.

Cup - distortion of a board characterized by dishing or deviation from flatness crosswise.

Defect - any irregularity in or on wood that may affect or limit its suitability for a particular end use.
- a. Sound defect - any defect presenting an essentially sound surface such as tight knots, stains, and pitch seams or pockets.
- b. Open defect - any defect creating a void or interruption of a solid surface, such as knotholes, insect holes, wane edge, and machine gouge.

Density - mass per unit volume, usually expressed as pounds per cubic foot; see also, "specific gravity."

Equalization treatment - controlled conditions applied in a dry kiln to bring lumber to a nearly uniform moisture content.

Equilibrium moisture content (EMC) - the moisture content at which wood reaches a balance with moisture conditions of the surrounding atmosphere, as determined by relative humidity and temperature.

Grain - the general direction of the fibers in wood or lumber.
- a. Cross grain - grain deviating in direction from the longitudinal axis of the piece of lumber.
- b. Short or end grain - terms applied to cross grain deviating sharply from the longitudinal axis of the piece; often irregular or swirled, as around knots.

Green-clipping - clipping green veneer to rough panel widths, or to narrower widths as necessary to remove inadmissible defects.

Heartwood - wood extending from pith to the sapwood, usually darker in color and with lower moisture content than sapwood.

Insect (borer) holes - oval, circular, or irregular holes in wood caused by larvae and adult insects.

Jointing - rendering the face or edge of a board perfectly straight and flat by passing it across a fixed cutter head.

Kerf - the cut made by a saw.

Knot - the part of a branch that has become incorporated into the trunk of a tree.
- a. Intergrown knot - that portion of a live branch which is firmly embedded in the trunk; a tight knot.
- b. Encased knot - that portion of a limb overgrown by the trunk after the branch dies; usually a loose knot.

Kraft overlay paper - a paper made from softwood neutral sulphate pulp, to which 20 percent by weight phenolic resin has been added; particularly noted for its strength.

Modulus of elasticity - a measure of the stiffness or rigidity of a member or material; i.e., resistance to deflection.

Modulus of rupture - a measure of the load, slowly applied, that a member or material will support for a short time.

Moisture content - the quantity of water in wood, expressed as percentage of the weight of the ovendry wood.

Parchmentized overlay paper - purified woodpulp paper treated by sulphuric acid or other chemicals to produce a hard, tough, water- and abrasion-resistant paper.

Particle board - an engineered panel product made from dry wood particles that have been coated with binder, formed, and hot pressed.

Patches, veneer - sound wooden plugs inserted in veneers to replace defective areas such as knotholes.

Pitch pocket or seam - an opening along the grain, often between two annual rings, containing pitch or resin.

Roundup - trimming irregularities and natural taper from a veneer bolt to obtain a right cylinder, preparatory to cutting usable veneer.

Sapwood - outer portion of a woody stem, extending from bark to heartwood, usually lighter in color and with higher moisture content than heartwood.

Scribner Decimal C log rule - a diagram-derived log rule designed to estimate the board-foot content of logs to the nearest 10 board feet.

Shelling - a separation of springwood and summerwood occurring during the manufacture of veneer, leaving a rough surface and irregular thickness; may be associated with excessive pressure bar compression or wide-ringed woods.

Shrinkage - contraction of wood caused by drying below fiber saturation point.

Sliced veneer - veneer cut from a flitch by a slicing machine rather than a rotary lathe.

Specific gravity - density or weight of wood per unit volume, expressed as a decimal proportion of the weight of an equal volume of water.

Stain - discoloration of wood caused by outside agents; common causes are the oxidation of extractives in the wood, and the growth of mold-like fungi in the wood.

Stress at proportional limit - stress in the extreme fibers of a member, at the limit at which deformation begins to occur at a rate greater than proportional to added load.

Sunken glue joint - depression along or adjacent to a glue line caused by further shrinkage of the wood about the glue line after final surfacing.

Telegraphing - a tendency of some furniture-core particle boards to transmit surface particle patterns or irregularities through face veneers; often referred to as "show-through."

Tension failure - failure of wood fibers in tension, or on the side of the member opposite the load.

Touch-sanding - a sizing operation consisting of sanding lightly to a specified panel thickness.

Twist - distortion of a board about its longitudinal axis, placing the corners in dissimilar planes.

Veneer - thin layers or sheets of wood cut from a log or flitch by a rotary lathe, slicer, or saw.

a. Tight side - the upper surface of the veneer sheet as it is cut; i.e., the surface opposite the lathe knife, and hence free of knife checks.
b. Loose side - the lower or inner surface of the veneer as it is cut; i.e., the surface adjacent to the lathe knife, exhibiting knife checks.

Vulcanized fiber - an unsized, unloaded sheet material made by treating cotton rag-base paper with a zinc chloride solution.

Wane - the presence of bark, or lack of wood, along the edge or corner of a board.

Warp - variation of a board or panel from a straight or true plane, including cup, bow, crook, and twist.

Agriculture — CSU, Ft. Collins

Barger, Roland L., and Fleischer, Herbert O.
1964. New products from low-grade ponderosa pine timber.
U. S. Forest Serv. Res. Paper RM-10, 54 pp., illus.
Rocky Mountain Forest and Range Experiment Station,
Fort Collins, Colorado.

Demonstrates the technical feasibility of producing types of plywood, particle board, overlaid siding, laminated beams, and laminated flooring. Products and manufacturing procedures either circumvent or tolerate the range of defect common in low-grade ponderosa pine sawtimber.

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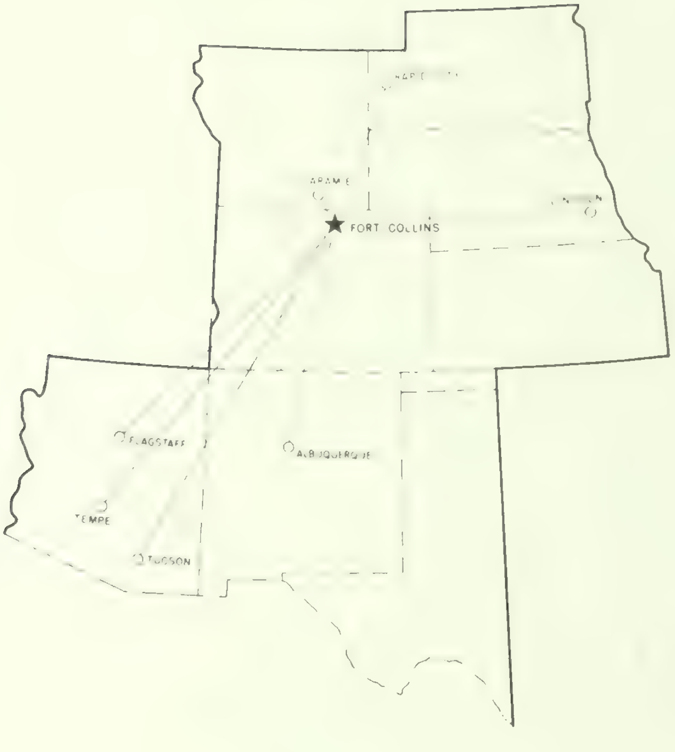
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ecember 1964 U.S. Forest Service Research Paper RM-11

Early- and Late-Season Grazing
Versus
Season-Long Grazing of Short-Grass Vegetation
on the
Central Great Plains

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ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION,
Fort Collins, Colorado Raymond Price, Director
FOREST SERVICE U.S. DEPARTMENT OF AGRICULTURE

ACKNOWLEDGMENTS

The author acknowledges the assistance of the following: W. M. Johnson, of the Rocky Mountain Forest and Range Experiment Station, U. S. Forest Service, who planned the study and was in charge of the field work 1943 to 1946; and Dr. David F. Costello, Former Chief, Division of Range Research, of the Rocky Mountain Station who supervised the study throughout its operation. The U. S. Soil Conservation Service cooperated in operating the experimental range, and officers, individual members, and range rider employees of the Crow Valley Livestock Cooperative Association gave counsel, suggestions, and cooperation in organizing and operating the field studies, furnishing the experimental cattle, and assisting in handling the cattle on the experimental range.

U.S. Forest Service Research Paper RM-11 December 1964

EARLY- AND LATE-SEASON GRAZING
VERSUS
SEASON-LONG GRAZING OF SHORT-GRASS VEGETATION
ON THE
CENTRAL GREAT PLAINS

by

Graydon E. Klipple, Range Conservationist[1]

Rocky Mountain Forest and Range Experiment Station[2]

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[1] Mr. Klipple was Range Conservationist with the Crops Research Division, Agricultural Research Service, U. S. Department of Agriculture, at the time of his retirement in January 1961.

[2] Central headquarters maintained in cooperation with Colorado State University at Fort Collins.

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Early- and Late-Season Grazing

Versus

Season-Long Grazing of Short-Grass Vegetation

on the

Central Great Plains

by

Graydon E. Klipple

Cattle that graze range vegetation of the short-grass association on the Central Great Plains usually produce much larger weight gains during May, June, and July than they do during August, September, and October. This has induced many cattle producers using short-grass rangelands to make large increases in the stocking of their range during the early period, and reduce the length of the grazing season. In this arrangement, steers are sold when the feed is utilized.

In the 1940's the Rocky Mountain Forest and Range Experiment Station received numerous inquiries as to the amount of increase in cattle weight gains per acre that could be expected from this early accelerated stocking practice, and the effect of the practice upon the range vegetation.

A study was made at the Central Plains Experimental Range[3] near Nunn, Colorado, to obtain information on these questions. This report summarizes results of the study.

EXPERIMENTAL DESIGN

Nine pastures were used: seven, approximately a half-section each, one, 400 acres, and one, 200 acres. They were divided into three blocks of three pastures each, with each block representing a different subtype of the short-grass association (table 1). These subtypes are typical of the short-grass vegetation of the Central Great Plains.

Grazing Treatments

Treatments were three different periods of grazing, designated as follows:

	Length of grazing period	Approximate dates
Season-long	6 months	May 10 - Nov. 10
Early grazing	3 months	May 10 - Aug. 10
Late grazing	3 months	Aug. 10 - Nov. 10

Cattle grazed in an early-grazed pasture were moved to the late-grazed pasture in the same block. Grazing treatments were randomized within blocks in 1943 and repeated without change each year from 1943 to 1952.

All pastures were grazed as nearly as possible to the same intensity--removal of approximately 40 percent by weight of the

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[3] *Operated at the time of the study by the Forest Service in cooperation with the Soil Conservation Service and the Crow Valley Livestock Cooperative Association on a portion of the northeastern Colorado Land Utilization Project.*

Table 1. --Experimental design of nine pastures with three types of grazing on three subtypes of short-grass range, Central Plains Experimental Range, 1943-52

Block number and subtype	Early grazing (May 10-Aug. 10)		Late grazing (Aug. 10-Nov. 10)		Season-long grazing (May 10-Nov. 10)	
	Pasture number	Area	Pasture number	Area	Pasture number	Area
		Acres		Acres		Acres
I - Blue grama[1] - buffalograss	1W	317	2N	400	15E	318
II - Blue grama - buffalograss - dry meadow	17N	320	17S	320	8SE	200
III - Fourwing saltbush - blue grama - buffalograss	13E	317	13W	320	24N	315
Total		954		1,040		833

[1] Common and botanical names of species are listed on page 16.

current growth of the short-grasses by the end of the assigned grazing period. Stocking rates for pastures grazed season-long were the estimated numbers of cattle required to make this utilization of the herbage by early November. Initially, stocking rates for the early-grazed pastures were two times the number of animals required to make this use of the herbage, if grazed season-long. These herds were transferred near August 10 each year, with little or no change in numbers, to the late-grazed pastures.

Differences in pasture size and productivity led to some variation from year to year in the number of yearling cattle grazed during the assigned grazing seasons (table 2). The season-long pastures developed more of this variation than the early-grazed or late-grazed pastures. Stocking was reduced in the early- and late-grazed pastures during the late years of the study. The average number of acres grazed per head for the period the cattle was grazed were 6.1, 6.6, and 13.1 acres during the early, late, and season-long grazing periods, respectively (table 3). The average number of acres per head-month of grazing was 2.03, 2.20, and 2.18 for the three conditions, respectively.

Utilization

Utilization of the vegetation was determined each year by an adaptation[4] of the ocular-estimate-by-plot method of Pechanec and Pickford.[5] Eighty plots were used in each pasture. Determinations were made on the early-grazed pastures immediately after removal of the cattle about August 10 each year; on the late-grazed and season-long pastures, during the week before or week after removal of the cattle near November 10 each year.

Average pasture utilization, with a few exceptions, was within the range of 30 to 50 percent of the vegetation growth produced each year (table 4). The apparent lower average utilization on the early-grazed pas-

[4] *Bement, R. E., and Klipple, G. E. A pasture-comparison method of estimating utilization of range herbage on the Central Great Plains. Jour. Range Mangt. 12: 296-298, illus. 1959.*

[5] *Pechanec, Joseph F., and Pickford, G. D. A comparison of some methods used to determine percentage utilization of range grasses. Jour. Agr. Res. 54: 753-765. 1937.*

Table 2.--Number of cattle[1] grazed, by pasture and grazing season, 1943-52

Grazing season and pasture number	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	10-year average[2]
	Number of cattle										
Early:											
1W	41	39	40	40	40	40	40	39	39	38	40
13E	60	60	60	60	60	60	60	57	60	56	59
17N	60	60	60	60	60	60	60	58	58	56	59
Total	161	159	160	160	160	160	160	154	157	150	158
Late:											
2N	40	42	40	38	40	40	40	39	39	38	40
13W	60	60	60	59	60	60	60	56	60	56	59
17S	60	60	60	60	60	60	60	58	58	56	59
Total	160	162	160	157	160	160	160	153	157	150	158
Season-long:											
15E	20	18	15	13	13	14	15	15	16	15	15
24N	29	30	26	28	29	28	34	33	33	32	30
8SE	15	18	19	19	18	19	18	18	18	18	18
Total	64	66	60	60	60	61	67	66	67	65	63

[1] Total animal months of grazing in a pasture divided by the number of months (3 or 6) in the grazing season, and quotient rounded to nearest whole number.

[2] Rounded to the nearest whole number.

tures than on the season-long and late-grazed pastures was not statistically significant.[6]

Thus the period of grazing in relation to the growth of the vegetation was the major factor influencing differences in vegetation changes found in this study.

[6] *Significance of differences between means were determined by t-test.*

Table 3.--Average number acres of rangeland grazed per head and per head-month, by grazing seasons, 1943-52

Grazing season and stocking rate	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	10-year average
	Acres										
Early:											
Per head	5.9	6.0	6.0	6.0	6.0	6.0	6.0	6.2	6.1	6.4	6.1
Per head-month	1.97	2.00	2.00	2.00	2.00	2.00	2.00	2.07	2.03	2.13	2.03
Late:											
Per head	6.5	6.4	6.5	6.6	6.5	6.5	6.5	6.8	6.6	6.9	6.6
Per head-month	2.17	2.13	2.17	2.20	2.17	2.17	2.17	2.27	2.20	2.30	2.20
Season-long:											
Per head	13.0	12.6	13.9	13.9	13.9	13.7	12.4	12.6	12.4	12.8	13.1
Per head-month	2.17	2.10	2.32	2.32	2.32	2.28	2.07	2.10	2.07	2.13	2.18

Table 4. --Grazing removal of current growth of vegetation, in percent by weight, by pasture and grazing season, 1943-52

Grazing season and pasture number	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	10-year average
						Percent					
Early:											36
1W	30	45	40	38	31	40	35	43	34	30	37
13E	32	40	35	43	30	36	33	34	33	32	35
17N	40	45	30	41	30	38	34	36	31	31	36
Late:											40
2N	45	42	45	42	32	41	38	38	39	42	40
13W	45	45	42	40	27	43	37	38	40	42	40
17S	50	40	40	44	28	45	38	40	40	39	40
Season-long:											39
15E	45	50	30	35	28	41	36	40	39	41	38
24N	35	40	45	39	27	42	39	42	41	41	39
8SE	25	45	40	49	32	42	37	43	41	42	40

Cattle Weights

Cattle were weighed within 1 or 2 days of the 10th of each month throughout the study. All cattle were weighed the same day at each monthly weighing. The 10th of the respective months has been used throughout this report as the beginning or end of grazing periods between weighing times.

The cattle-weighing practice was to gather the cattle from the pastures during an afternoon, hold them in a corral overnight without feed or water, weigh them early the next morning, and return them to their pastures. Each animal was weighed individually 1943 through 1949. The cattle were weighed by pasture herds during 1950, 1951, and 1952.

Cattle grazed were yearling Herefords of good to choice grade. Both steers and heifers were used each year. Each pasture herd, however, was of only one sex, and at no time were steer results from one grazing period compared with heifer results from another grazing period. Steer and heifer weight gains were combined in computing grazing-season average weight gains each year, and 10-year averages.

The cattle were from 10 to 15 ownerships. They were assigned to pasture herds from ownership herds within sex classes by lot each year. The number assigned to a pasture from any one sex-ownership herd was in the same ratio to the total number of head assigned to the pasture as the number in the sex-ownership herd was to the total number of that sex in all ownerships. One or more head belonging to each owner was in each pasture herd each year. This procedure minimized the effects of differences in cattle quality and cattle wintering conditions among the ownership herds.

Vegetation Measurements

Vegetation measurements used to evaluate the influence of the treatments were as follows:

1. Square-foot-density measurements[7] by species were made on 40 permanent, 5-

---

[7] *Stewart, George, and Hutchings, S. S. The point-observation-plot (square-foot-density) method of vegetation survey. Amer. Soc. Agron. Jour. 28: 714-722, illus. 1936.*

foot-square plots per pasture in 1940, 1941, and 1942, before the study started; and in 1946, 1947, 1948, 1951, 1953, 1955, and 1956.

2. Grass herbage yields were measured by clipping plots in 1943, 1949, 1950, 1951, and 1953. Twenty-four plots, 6 inches wide by 30 feet long, were clipped per pasture in 1943. Eighty plots, 1 by 2 feet in size, were clipped per pasture in the later years.

Climate and Weather

Weather at the Experimental Range during the 10 years of study was near normal. Temperatures and wind movement were not unusual. The usual, relatively large, year-to-year variations prevailed in the total annual and growing-season (May-September) precipitations. The total annual precipitation at the headquarters, and the average of 24 gages in the pastures for the growing season, in inches of water, for the 10 years were as follows:

	Precipitation	
Year	Total annual	Growing season
	(Inches)	(Inches)
1943	7.78	5.88
1944	8.17	4.41
1945	12.27	8.88
1946	11.79	8.33
1947	15.53	11.06
1948	7.92	5.82
1949	13.52	9.98
1950	11.90	9.75
1951	13.10	8.63
1952	14.10	9.44
10-year average	11.61	8.22

Both of these 10-year averages were only slightly less than the 20-year (1939-58) averages of 11.84 and 8.46 inches, respectively, that are the long-time averages at the Experimental Range.

EXPERIMENTAL RESULTS

Cattle Weight Gains

Weight Gains per Head

The 10-year average weight gain per head between May 10 and August 10 on the early-grazed pastures was 170 pounds (table 5). This was 9 pounds less than the 179-pound average gain produced by the cattle in the season-long pastures during the same 3-month period, a difference that was not significant. Weight gains per head in the early-grazed pastures were larger than in the season-long pastures during the same period in only 2 of the 10 years (fig. 1). The 41-pound larger gain per head made in the season-long pastures in 1948 was the only difference of this comparison that was statistically significant. This lack of difference in weight gains is of interest, because for the 3-month period the season-long pastures received only half the grazing of the early-season pastures, and intensity of grazing often affects weight gains per animal. In this early-season grazing, it did not.

Two factors--the volume of vegetation regrowth after August 10, and the length of time for vigorous new growth in the spring--appeared to influence to a marked degree the average cattle weight gains made per head on the early-grazed pastures. Good fall regrowth and early new growth the following spring occurred each of the 5 years when the average gain per head produced on the early-grazed pastures exceeded 180 pounds. Ample old vegetation was on the early-grazed pastures in the spring of 1948, but sufficient moisture for vigorous new growth was not received until late June. Average per-head gain to July 10 that year was only 59 pounds. For reasons discussed later, the cattle in the season-long pastures in 1948 had access to a larger volume of cool-season species such as western wheatgrass and needle-and-thread. The cattle that grazed the season-long pastures produced an average gain of near 60 pounds during the May 10-June 10 period, but their average production dropped to 36 pounds per head during the June 10-July 10 period.

Ten years of accelerated stocking of the early-grazed pastures did not significantly reduce the average weight gains produced per head. The average per-head gains during the last 4 years of this study compared just as favorably with the average per-head, May 10-August 10, gains produced on the season-long pastures during the same period as they did during the first 4 years.

Table 5.--Average cattle weights and weight gains per head (steer and heifer data combined) by weighing date and grazing season, 1943-52

Grazing season and weight record	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	10-year weighted average[1]
						Pounds					
Early:											
May 10	394	398	430	420	414	433	413	424	424	445	419
August 10	596	582	593	575	598	553	597	574	602	629	589
3-month gain	202	184	163	155	184	120	184	150	178	184	170
Late:											
August 10	596	582	593	575	598	553	597	574	602	629	589
November 10	703	688	685	653	675	663	685	687	685	717	683
3-month gain	107	106	92	78	77	110	88	113	83	88	94
6-month gain (Early plus late)	309	290	255	233	261	230	272	263	261	272	264
Season-long:											
May 10	391	414	420	406	378	430	399	421	400	408	407
August 10	581	614	604	574	564	591	594	582	581	574	586
3-month gain	190	200	184	168	186	161	195	161	181	166	179
November 10	683	730	701	676	656	682	683	691	660	670	684
3-month gain	102	116	97	102	92	91	89	109	79	96	98
6-month gain	292	316	281	270	278	252	284	270	260	262	277

[1] Weighted for variation in the number of animals contributing to the yearly averages, and rounded to nearest whole digit.

The average gains per head after the cattle were moved to the late-grazed pastures on August 10 were much smaller than those produced up to August 10. It is of interest that early and late gains appeared to be related (fig. 2). Early gains were high in 1943, 1947, 1949, 1951, and 1952. Four of these 5 years were the years of lowest late-season gains. Contrarily, 1948 and 1950 were years of poor early gains followed by good late-season gains.

Lower gains per head also were obtained during the second 3 months of the season-long grazing treatment. The average per-head weight gains produced in the late-grazed and season-long pastures during the August 10-November 10 period were not significantly different in any one of the 10 years (fig. 3).

Average monthly weight gains per head produced on the early-grazed pastures were quite similar to those produced on the season-long pastures, during the same monthly periods, for almost all of the 10 years (fig. 4). Only one of the 30 monthly differences--that for the period ending June 10, 1948--was statistically significant. Likewise, the average per-head monthly gains produced on the late-grazed pastures were quite similar to those produced on the season-long pastures during the same monthly periods.

The cattle lost weight in the late-grazed pastures during the October 10-November 10 period in 4 of the 10 years, and only one-half pound was gained during that period in a fifth year. Weight losses were also experienced during that period in 1 year, and gains were

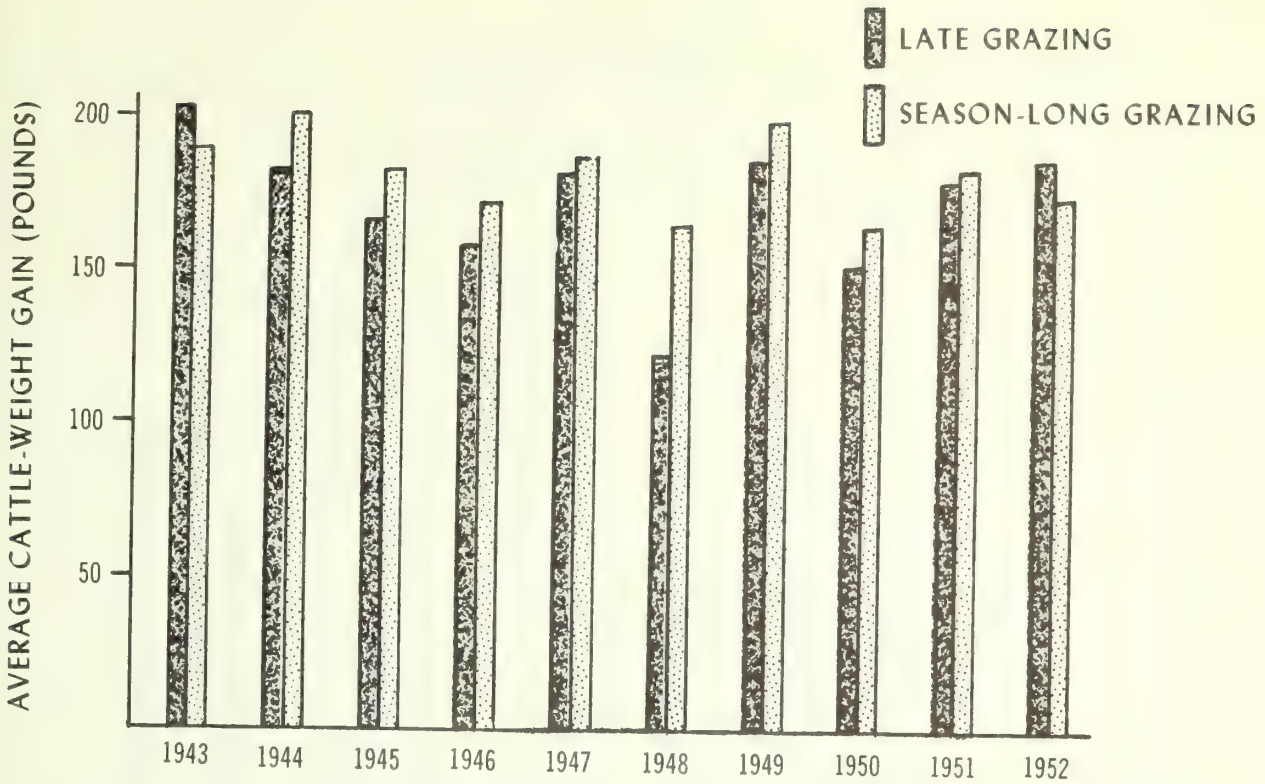

Figure 1.--Average cattle weight gains per head produced in early-grazed and season-long pastures during May 10-August 10 period each year, 1943-52.

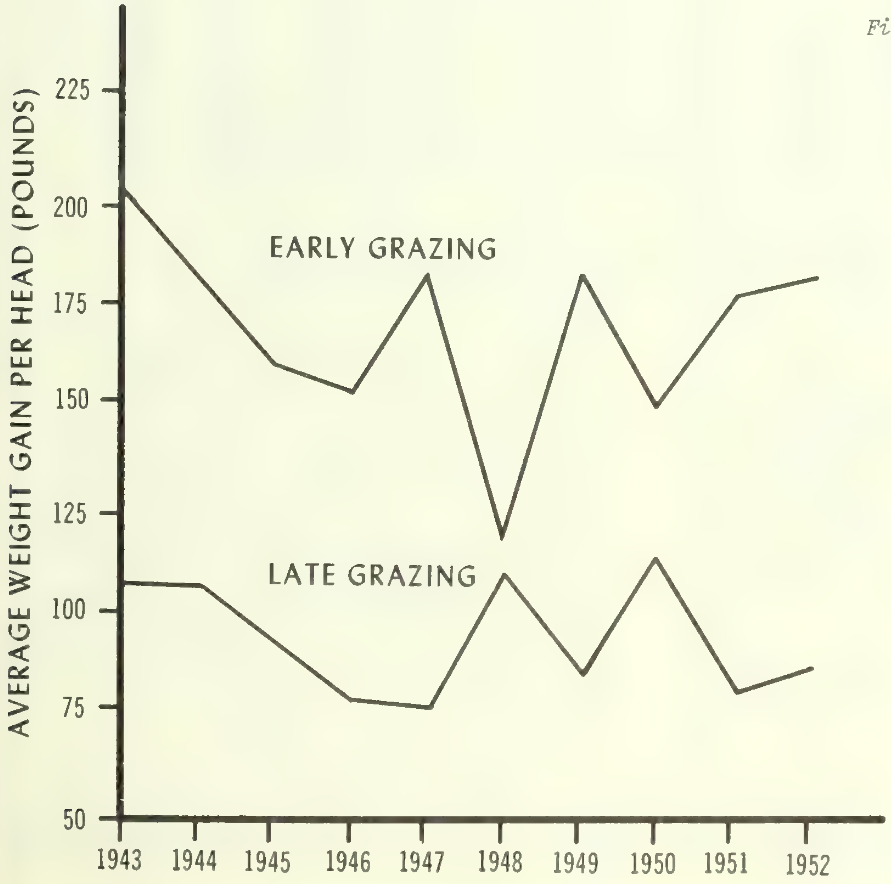

Figure 2.--Average pounds of weight gain produced per head during early grazing and late grazing by years, 1943-52.

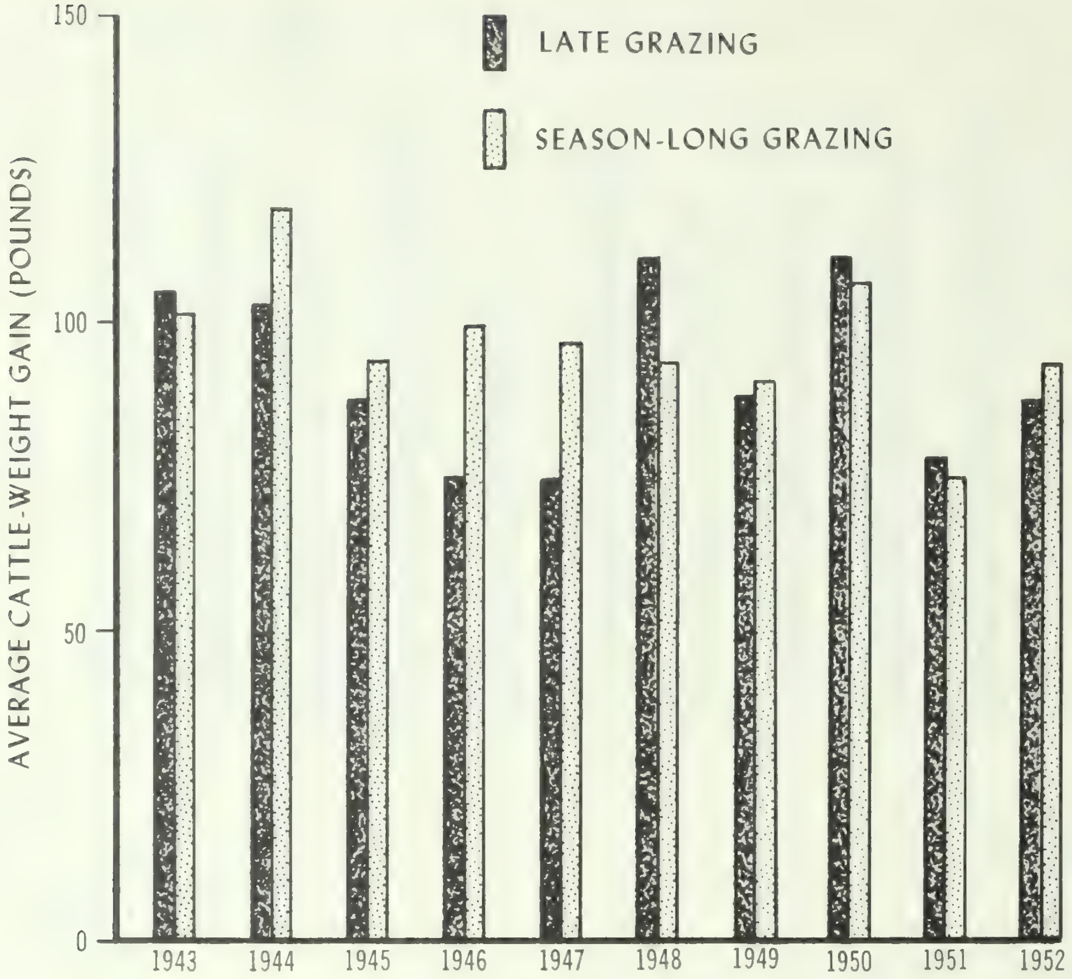

Figure 3.--Average cattle weight gains per head produced in late-grazed and season-long pastures during August 10-November 10 period each year, 1943-52.

less than 5 pounds per head in 2 other years by the cattle in the season-long pastures. Only in 2 years were gains of more than 10 pounds per head made during this period under each treatment. These results, and similar results from other grazing-management studies that used yearling cattle to graze short-grass range vegetation,[8] [9] indicate the advisability of moving yearling cattle intended for fall sale to market prior to mid-October.

Weight Gains per Acre

Early grazing produced larger weight gains per acre than season-long grazing every year, and the differences were significant in 8 of the 10 years (fig. 5). The 7-pound difference between the 10-year average gains per acre was highly significant. Also, the weight gains per acre from the season-long grazing were larger than those made from late grazing in all years, and the differences were significant in 9 of the 10 years. The 6.8-pound difference between the 10-year average weight gains per acre was highly significant. Cattle grazed on

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[8] *Klipple, G. E., and Costello, David F. Vegetation and cattle responses to different intensities of grazing on short-grass ranges of the Central Great Plains. U. S. Dept. Agr. Tech. Bul. 1216, 82 pp., illus. 1960.*

[9] *Launchbaugh, J. L. Jr. The effect of stocking rate on cattle gains and on native shortgrass vegetation in west-central Kansas. Kans. Agr. Expt. Sta. Bul. 394, 29 pp., illus. 1957.*

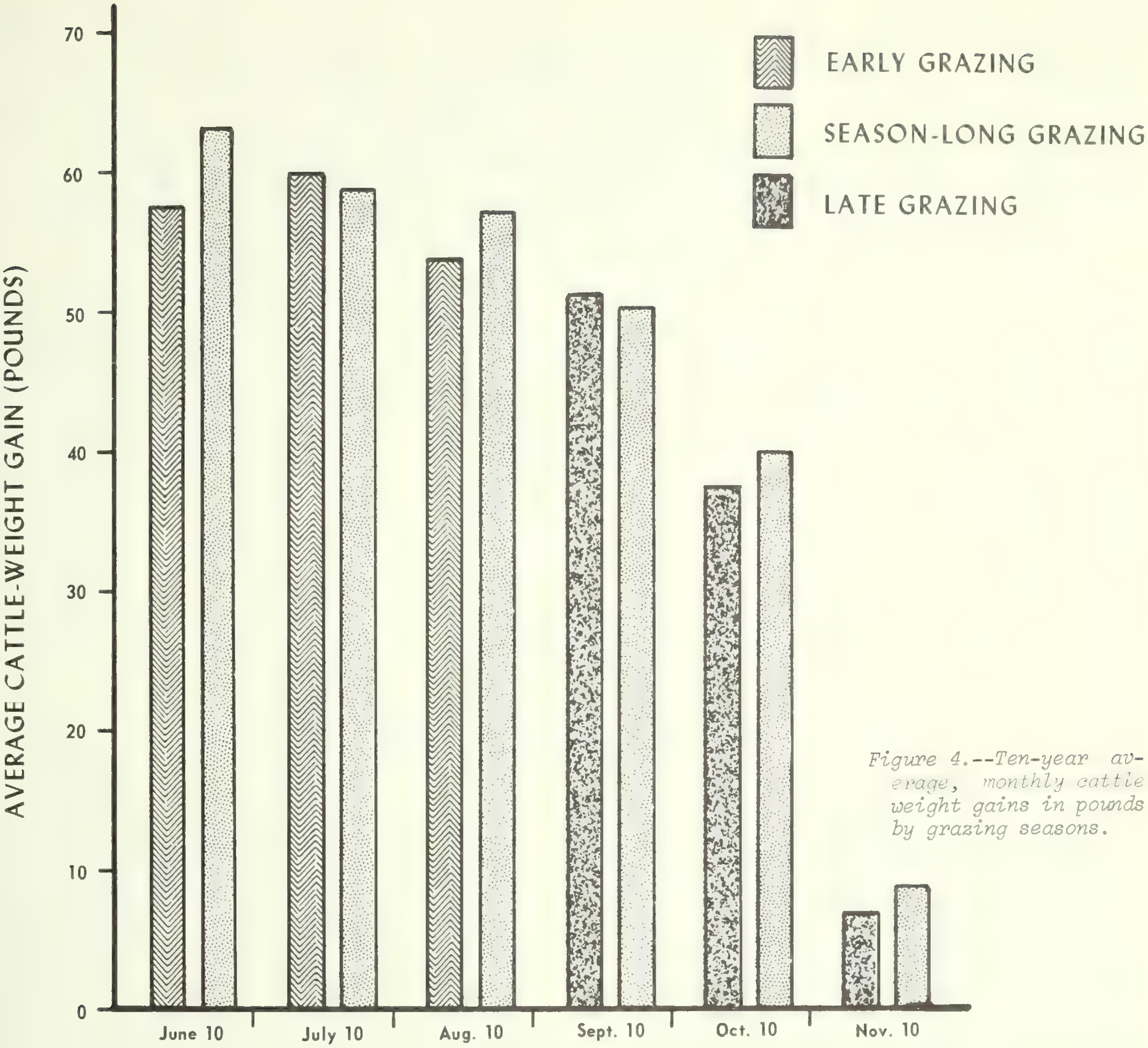

Figure 4.--Ten-year average, monthly cattle weight gains in pounds by grazing seasons.

the season-long pastures produced average weight gains per acre approximately intermediate between those on the early-grazed and late-grazed pastures. It is interesting that the general seasonal average gain per acre of the cattle grazed on the same area season-long was 21.1 pounds, compared with 21.2 pounds when the cattle grazed one area for the first 3 months and then were moved to the second area for the last 3 months.

Effects on the Range Vegetation

Approximately equal amounts of forage were removed during each of the three grazing periods (see table 4). Each grazing period, however, represented a different time in the growth cycle of the grazed species. Early grazing removed the forage of most species during the time of lush vegetative growth. Late grazing removed the forage during the time the vegetation was maturing and during early dormancy. Season-long grazing spread the forage removal over the total time period of both early and late grazing, but the intensity of forage removal was much lighter each day.

The reaction of the vegetation to the time of grazing was studied from the standpoint of changes in ground cover: by the total vegeta-

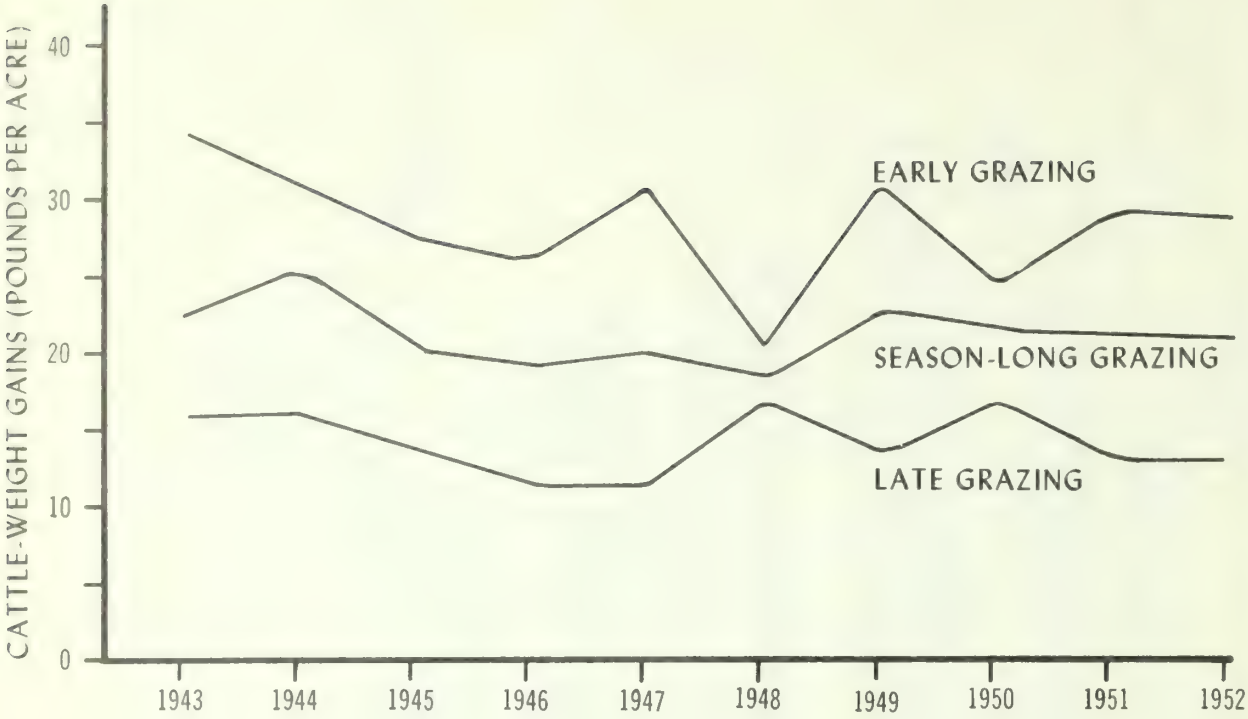

Figure 5.--Average cattle weight gains in pounds per acre by grazing seasons and years, 1943-52.

tion, by botanical groups of species, by a few individual species that produced large percentages of the forage, and by a few individual undesirable species. Changes in the composition of the vegetation, and changes in the per-acre production of herbage by the short-grass and mid-grass groups of grazed species, were also studied. Data from the 1951 and 1953, and the 1955 and 1956 examinations of the vegetation on six pastures were also compared for possible effects of the seasons of grazing on the way the vegetation reacted to the acute drought of 1954.

Changes in Ground Cover

Square-foot-density measurements were made on the same observation plots, thereby reducing sampling errors. The effects of year-to-year climatic variations on vegetation measurements, also, were reduced by combining data for a 3-year period at the beginning and middle of the study, and a 2-year period at the end.

The first period of examination, 1940-42, preceded the start of the study. All 3 years were favorable for plant growth. That period, however, had been preceded by several years of below-average rainfall that began in 1934 and culminated in the acute drought of 1939. All pastures used in the study were grazed lightly or moderately during the 1940-42 period. The vegetation was in high-fair or better condition by 1943.

At the start of the study, the vegetation on experimental pastures was quite similar as to total cover (table 6). The only significant difference observed was the 2.24 percent average difference between the early-grazed and season-long pastures. No significant differences were found in the middle and final sampling periods. The total vegetation cover on all three groups of pastures was less at the close of the experiment than at the start.

Grasses and grasslike plants as a group made up most of the cover for all three grazing treatments in all sampling periods. They

Table 6.--Average percentage of ground surface covered by live vegetation of principal species by botanical groups, grazing treatments, and time periods

Botanical groups and species	Early grazing			Late grazing			Season-long grazing		
	1940 1941 1942	1946 1947 1948	1951 and 1953	1940 1941 1942	1946 1947 1948	1951 and 1953	1940 1941 1942	1946 1947 1948	1951 and 1953
	Percent								
Grass and grasslike:									
Alkali sacaton	0.06	0.13	0.06	0.07	0.10	0.11	0.05	0.59	0.28
Blue grama	8.80	9.68	7.58	6.26	7.42	6.02	5.11	7.40	5.10
Buffalograss	.28	.23	.29	.63	.70	.29	2.01	2.04	1.57
Inland saltgrass	.29	.11	.06	.38	.11	.09	.06	.09	.29
Needle-and-thread	.03	.07	.02	.08	.10	.08	[1] T	.01	.01
Ring muhly	.02	.01	.01	.05	.02	.03	.34	.25	.13
Sand dropseed	.02	.01	.03	.02	.02	.05	.02	.10	.05
Three-awns	.14	.17	.33	.30	.24	.33	.44	.61	.30
Western wheatgrass	.17	.05	.02	.28	.16	.06	.28	.18	.04
Sedges	.02	.02	.02	.02	.07	.11	.02	.08	.01
Other grasses	.04	.01	.01	.08	.06	.03	.28	.07	.01
Total	9.87	10.49	8.43	8.17	9.00	7.20	8.61	11.42	7.79
Forbs:									
Cryptantha	.20	T	.01	.26	.02	.01	.15	.02	.01
Goosefoots	.28	T	T	.31	.02	.02	.20	T	T
Milkvetches	.02	T	.01	.01	.08	.03	.06	.03	.01
Poverty sumpweed	--	.01	T	.14	.05	.04	.02	T	T
Prairie sunflower	.06	T	T	.10	.02	.01	T	--	--
Rush skeletonplant	.02	T	T	.02	.01	.01	.02	T	T
Russianthistles	.02	T	T	.11	T	.01	.04	T	T
Scarlet globemallow	.40	.04	.01	.29	.06	.03	.19	.10	.01
Scurfpeas	.16	.01	T	.20	.09	.03	.06	T	.03
Silky sophora	.05	.01	.01	.05	.02	T	.07	.03	.01
Slenderbush eriogonum	.16	.06	.16	.37	.22	.14	.21	.15	.10
Tansyleaf aster	.04	T	.01	.23	T	.01	.24	T	T
Other forbs	.14	.04	.03	.26	.07	.01	.35	.05	.02
Total	1.55	.17	.24	2.35	.66	.35	1.61	.38	.19
Browse:									
Broom snakeweed	.04	.04	.02	.01	.07	.03	.07	.11	.03
Fourwing saltbush	.62	.33	.34	.45	.31	.15	.21	.11	.12
Fringed sagebrush	.13	.09	.20	.07	.13	.09	.07	.04	.06
Plains pricklypear	.88	.32	.32	.83	.39	.47	.29	.17	.29
Rubber rabbitbrush	.24	.12	.05	.10	.20	.11	.22	.27	.11
Other browse	--	.06	.01	.03	.02	.01	.01	.03	T
Total	1.91	.96	.94	1.49	1.12	.86	.87	.73	.61
Total vegetation	13.33	11.62	9.61	12.01	10.78	8.41	11.09	12.53	8.59

[1] T = less than 0.005 percent.

increased between the first and middle time periods under all three grazing treatments, but only the average increase in the season-long pastures was significant. Grass and grasslike plants as a group lost cover in all three grazing treatments between the middle and final period of sampling. The season-long pastures suffered the largest loss, the early-grazing less, and late-grazing the least. Below-average growing conditions during the later years of the experiment are believed to be a major contributing factor to these decreases.

The reactions of the important forage species to the three treatments are of value to sound grazing management of this type of range vegetation. Blue grama was the dominant species on all pastures. It was present on 95 percent of the plots on the early-grazed pastures in the 1940-42 sampling period, and on 99 percent of the plots during the two later periods. It had average frequencies of 87, 90, and 96 percent on the late-grazed pastures; and 79, 91, and 89 percent on the season-long pastures, respectively, during the first, middle, and final examination periods. Blue grama, as measured by cover, increased under all grazing treatments between the initial and middle periods of observation and then decreased. The greatest increase between the first two periods was under season-long grazing and the least under early grazing. The subsequent reductions in blue grama cover were such that the overall change for the period of study was a significant reduction under the early-grazing treatment, and essentially no change under the late-season and season-long treatments.

Buffalograss was the second most important grass on the pastures. It maintained its ground cover on the early-grazed pastures, but lost on the late-grazed and the season-long pastures.

Western wheatgrass was second to blue grama in frequency of occurrence among the grasses, but usually made less cover than buffalograss. Three-awns were a close third. Western wheatgrass was reduced under all three grazing treatments. Other grasses such as needle-and-thread, alkali sacaton, sand dropseed, and inland saltgrass were minor parts of the cover and made no significant changes during the period of study.

Forbs as a group averaged 1.55, 2.35, and 1.61 percent cover respectively on the early-grazed, late-grazed, and season-long pastures during the 1940-42 period. Their total cover during the two later periods was only a fraction of a percent on all three groups of pastures. Annual forbs provided approximately one-half to two-thirds of the forb cover at the start of the study. Many were entirely absent or appeared only as occasional plants during the later sampling periods. Perennial forbs such as scarlet globemallow, the good forage species, the leguminous scurfpeas and silky sophora, and slenderbush eriogonum, a poor forage, usually decreased on the average from the first to the last sampling period.

Scarlet globemallow and blue grama were the only species that occurred on more than 50 percent of the plots. Globemallow is high in protein, is freely grazed by cattle, and usually is available by early May. It decreased on all pastures on all treatments.

Scurfpeas were the only other perennial forbs grazed regularly. They all but disappeared from the early-grazed pastures, and showed major losses in cover on the late-grazed and season-long pastures. Several of the annual forb species, when available, were grazed by the cattle. Annual forbs, however, are too uncertain to be considered as a regular source of forage.

Cover of browse species as a group declined from the initial to the later periods of observation. Most of this loss was between the 1940-42 and 1946-48 periods. Fourwing saltbush and plains pricklypear were the chief species contributing to these losses. Changes by other browse species varied considerably among the grazing treatments. Over the period of study, total browse cover was significantly reduced on the early-grazed and late-grazed pastures but not on the season-long pastures.

Fourwing saltbush was the only browse species that the cattle grazed freely. This species had lost approximately half of its 1940-42 cover by 1946-48 on the early-grazed and season-long pastures, and then maintained itself during the later years. It was progressively reduced on the late-grazed pastures. Fourwing saltbush had significantly lower cover at the end of the study than it had at the start on both the early-grazed and late-grazed pastures.

Broom snakeweed and rubber rabbitbrush lost cover on the early-grazed and season-long pastures, and approximately maintained themselves on the late-grazed pastures. Fringed sagebrush increased on the early-grazed pastures between the middle and final examination periods. It was quite conspicuous in the remaining vegetation at the close of the early grazing period during the later years of the experiment. Fringed sagebrush approximately maintained itself on the late-grazed and season-long pastures.

Plains pricklypear is an undesirable species in the short-grass association over wide areas of the Central Great Plains. Its average cover was approximately equal to or larger than the average cover of any one other browse species throughout this experiment on all of the pastures. The general reactions of this species to the grazing seasons were loss in cover on the early-grazed and late-grazed pastures and maintenance on the season-long pastures.

Changes in the Composition

The more important changes in the composition of the vegetation were the decreases in the forbs between the initial and middle examination periods, and the increase in blue grama during that time interval. These changes were quite similar under all three grazing treatments. Changes in percentage composition between 1946-48 and 1951 and 1953 were small. Forb and browse species were contributing proportionately less and grass species more at the close of the study than when it began. The grazing treatments did not develop any significant changes in the composition of the vegetation.

Changes in Herbage Production

Herbage production and changes in herbage production over a period of years are the more reliable measures of the impact of grazing management procedures. The average yields in pounds per acre by the two groups of grasses and sedges--short-grasses and sedges, and mid-grasses--on the three pastures in each grazing season for 1 year early in the experiment, 1943; for 3 years late in the experiment; and for 1953, the year following the close of the grazing treatments, are listed in table 7.

In 1943, at the start of the study, average yields of short-grass herbage on the early-grazed and late-grazed pastures were larger than on the season-long pastures. Mid-grass herbage yields were similar for all treatments that year. Both short-grass and mid-grass yields were less in 1949 than in 1943 for all three treatments.

Short-grass yields under season-long grazing increased to an average 602 pounds per acre in 1953, significantly larger than the 498 pounds produced in 1943. On the late-grazed pastures, average yield of short-grasses was 653 pounds in 1953, larger than the 467 pounds obtained in 1949, but smaller than the 743-pound average yield obtained in 1943. The early-grazed pastures produced 535-pound average yield in 1953, which was not significantly larger than either the 514 pounds produced in 1949 or the 460 pounds produced in 1950. It was significantly smaller than the 712-pound average yield produced in 1943.

Mid-grass herbage yields continued to decline under all grazing treatments. Decreases were most severe on the early-grazed pastures, and about the same on the late-grazed and season-long pastures. The 1953 yield of mid-grass herbage was only approximately 10 percent of what it had been in 1943 on the early-grazed pastures, compared with approximately 38 and 40 percent for the late-grazed and season-long pastures.

In general, total production was maintained on the season-long pastures but reduced under early-grazing and late-grazing. The loss was greatest on the early-grazed pastures. Lack of grazing after July, if it benefited the vegetation at all, did not provide sufficient benefit to offset the adverse effects of accelerated

Table 7.--Average herbage production of air-dry hay by forage groups and grazing seasons, 1943, 1949, 1950-53

Grazing seasons and forage groups	1943	1949	1950	1951	1953
	Pounds per acre				
Early:					
Short-grasses and sedges[1]	712	514	460	601	535
Mid-grasses[2]	206	137	83	99	20
Total	918	651	543	700	555
Late:					
Short-grasses and sedges	743	467	499	481	653
Mid-grasses	230	183	173	193	88
Total	973	650	672	674	741
Season-long:					
Short-grasses and sedges	498	381	305	403	602
Mid-grasses	231	171	128	133	92
Total	729	552	433	536	694

[1] Blue grama, buffalograss, and fine-leaf sedges.

[2] Western wheatgrass, needle-and-thread, sand dropseed, alkali sacaton, inland saltgrass, little bluestem, prairie sandreed, and side-oats grama.

stocking during the early part of the growing season.

Reaction of Vegetation to 1954 Drought

Data from six of the nine pastures, two in each grazing treatment, were analyzed to determine possible effects of past grazing-season treatments upon the way the range vegetation came through the 1954 acute drought. Averages of the data for 1951 and 1953 were compared with the average data for 1955 and 1956. No real differences were found due to treatment. Major individual species and botanical groups of species reacted alike to the drought conditions on all six pastures. Ground cover of the more palatable grasses was reduced by the drought. Alkali sacaton and inland saltgrass, found where shallow water tables exist, increased in ground cover. Forbs, both desirable and undesirable, increased in ground cover, with annual forbs making the larger increases. The deep-rooted, more desirable browse species--fourwing saltbush and common winterfat--increased in ground cover while the poor-forage and nonforage browse species did not change or lost in ground cover.

Mechanical Impact of Concentrated Stocking

Some undesirable conditions developed under the concentrated use of the early 3-month period. Cow-path gullies developed far more rapidly on the early-grazed pastures than they did on the season-long or late-grazed pastures. The increased trailing to and from salt and water resulted in loose soil in the cattle trails, which blew and washed away.

Two partially healed blowout areas, one on sandy land in early-grazed pasture 13E, and one on heavy soil in early-grazed pasture 17N, became active again during the study. These areas were near water, and the cattle used them for resting and rubbing. Practically no revegetation of open soil occurred on the pastures subjected to early grazing. Some of the cattle trails became relatively deep.

In contrast, buffalograss became established on portions of a number of trails on the season-long pastures during the early years of the study. A few new trails opened up during the later years of the study, however, on those pastures that were less favorable for plant growth. On the late-grazed pastures, perennial grasses also became established on a number of cattle trails that were bare soil at the start of the experiment in 1943. Several small gullies, active when the study started, became inactive in the late-grazed pastures during the 10 years. Taller vegetation, especially Russianthistle, that grew on many of the cattle trails in the late-grazed pastures during the May-July period often induced the cattle to make new trails. Thus many of the trails on the late-grazed pastures were used for only 1 or 2 years before they were abandoned. The trails did not become so deep, and they often had a chance to become partially covered with perennial vegetation before they were used again.

SUMMARY

A grazing experiment was conducted on the Central Plains Experimental Range near Nunn, Colorado from 1943 through 1952 to compare (1) increased stocking during a 3-month early grazing period (May 10-August 10, approximately) followed by a second 3 months on other pastures that had been deferred during the early period, with (2) average stocking during a 6-month season-long grazing period (May 10-November 10, approximately).

Three groups of three pastures were used in the experiment to allow for three randomized replications of each grazing period. Each of the nine pastures was grazed for 10 years during the period assigned to it.

The number of cattle grazed for the 3-month period was approximately two times the number grazed for the 6-month period. Stocking objectives on all treatments were to make moderate utilization of the current growth of the herbage during the period of grazing. Pasture herds were moved from the early-grazed to the late-grazed pastures in the same block with practically no change in numbers. The moderate intensity of herbage removal was obtained quite regularly throughout the experiment.

Both yearling steers and yearling heifers were grazed. The two sexes were kept separate at all times, and all three herds used in a block of pastures during any one year were of the same sex. Weight gains on steers and heifers were combined in determining average weight gains per acre.

Cattle concentrated on the early-season pastures made about the same gains each month as cattle grazing on the season-long pastures at the same time. Also, cattle concentrated on the late-season pastures made about the same gains each month as those grazing the season-long pastures. Because more cattle were concentrated in the early-grazed pastures, significantly larger average weight gains per acre were made than on the season-long pastures. Likewise, because cattle were not on the late-grazed pastures during the early period when best gains were made, significantly smaller average weight gains per acre were made on the late-grazed pastures than on the season-long pastures.

The vegetation on the early-grazed pastures suffered significant losses in herbage production. The pastures also suffered mechanical damage to the vegetation and soil from the heavier stocking for a shorter time period.

The vegetation on the late-grazed pastures also lost some in production but there was no mechanical damage. Loss in ground cover from die-out of entire clumps of blue grama during relatively short, 3- to 4-week periods of hot dry weather in late July and August, followed rather luxuriant early-season growth. These losses were quite heavy in 1948 after a year of high blue grama production in 1947.

The vegetation on the pastures grazed season-long maintained production during the 10 years of the experiment.

COMMON AND BOTANICAL NAMES OF SPECIES MENTIONED

GRASSES AND GRASSLIKE PLANTS

Alkali sacaton	*Sporobolus airoides* Torr.
Blue grama	*Bouteloua gracilis* (H. B. K.) Lag.
Buffalograss	*Buchloe dactyloides* (Nutt.) Engelm.
Inland saltgrass	*Distichlis stricta* (Torr.) Rydb.
Little bluestem	*Andropogon scoparius* Michx.
Needle-and-thread	*Stipa comata* Trin. & Rupr.
Prairie sandreed	*Calamovilfa longifolia* (Hook.) Scribn.
Ring muhly	*Muhlenbergia torreyi* (Kunth) Hitchc.
Sand dropseed	*Sporobolus cryptandrus* (Torr.) A. Gray
Side-oats grama	*Bouteloua curtipendula* (Michx.) Torr.
Three-awns	*Aristida* spp.
Western wheatgrass	*Agropyron smithii* Rydb.
Sedges	*Carex* spp.

FORBS

Cryptantha	*Cryptantha* spp.
Goosefoots	*Chenopodium* spp.
Milkvetches	*Astragalus* spp.
Poverty sumpweed	*Iva axillaris* Pursh
Prairie sunflower	*Helianthus petiolaris* Nutt.
Rush skeletonplant	*Lygodesmia juncea* (Pursh) D. Don.
Russian thistles	*Salsola* spp.
Scarlet globemallow	*Sphaeralcea coccinea* (Pursh) Rydb.
Scurfpeas	*Psoralea* spp.
Silky sophora	*Sophora serecia* Nutt.
Slenderbush eriogonum	*Eriogonum microthecum* Nutt.
Tansyleaf aster	*Aster tanacetifolius* H. B. K.

BROWSE

Broom snakeweed	*Gutierrezia sarothrae* (Pursh) Britt. & Rusby
Common winterfat	*Eurotia lanata* (Pursh) Moq.
Fourwing saltbush	*Atriplex canescens* (Pursh) Nutt.
Fringed sagebrush	*Artemisia frigida* Willd.
Plains pricklypear	*Opuntia polyacantha* Haw.
Rubber rabbitbrush	*Chrysothamnus nauseosús* (Pall.) Britt.

GPO 847-633

Klipple, Graydon E.
1964. Early- and late-season grazing versus season-long grazing of short-grass vegetation on the Central Great Plains. U. S. Forest Serv. Res. Paper RM-11, 16 pp., illus.

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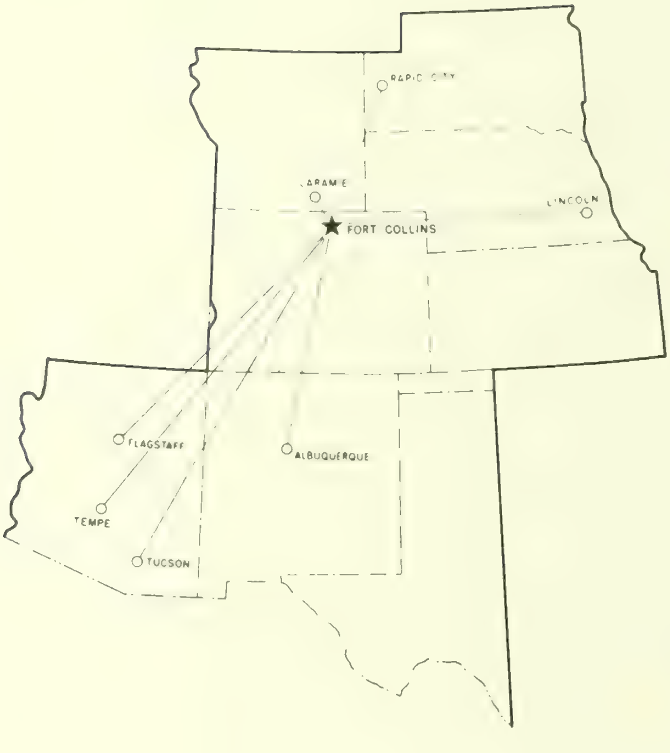
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ULTIPURPOSE PREFABRICATED CONCRETE CHECK DAM

by

Burchard H. Heede

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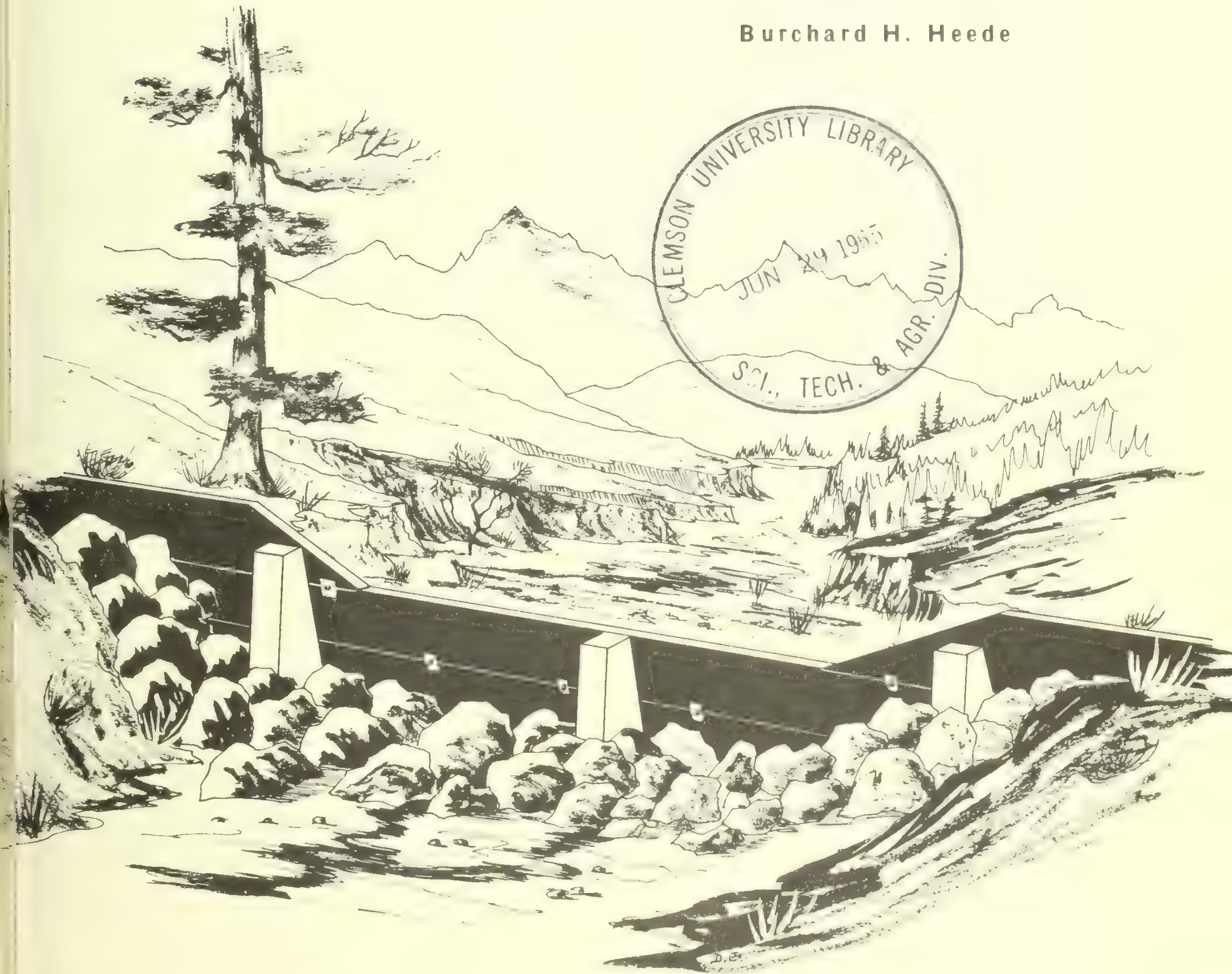

ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION
RAYMOND PRICE, DIRECTOR FORT COLLINS, COLORADO
FOREST SERVICE U. S. DEPARTMENT OF AGRICULTURE

U. S. Forest Service Research Paper RM-12 March 1965

MULTIPURPOSE PREFABRICATED CONCRETE CHECK DAM

by

Burchard H. Heede, Associate Hydraulic Engineer

Rocky Mountain Forest and Range Experiment Station[1]

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[1] Central headquarters maintained in cooperation with Colorado State University at Fort Collins.

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Multipurpose Prefabricated Concrete Check Dam

by

Burchard H. Heede

NEED FOR A NEW DESIGN

A new design was needed to simplify the construction of check dams in fairly inaccessible mountain forest areas. Often suitable materials are not available locally, or check dams built from these local materials require various types of equipment, large amounts of labor, and intensive supervision.

A prefabricated, partially prestressed concrete check dam[2] has been designed, built, and installed in a gully in western Colorado (fig. 1). This type of structure should prove useful for future gully control projects, stream gage cutoff walls, and other applications.

DESIGN OBJECTIVES

The objectives for the design were to develop a structure (1) composed of units of predetermined size, (2) suited to mass production, (3) requiring a minimum of labor, machinery, and supervision, and (4) adaptable to a wide variety of sites and situations.

The feasibility of gully control is to a great extent a cost problem. This is especially true for the remote mountain areas of the National Forests in Colorado, where present land values are low and where flood flows do not directly endanger human life and property. Therefore, cost aspects also guided the design of the prefabricated check dam.

Naturally, costs are always involved in or influenced by a design. Yet, some cost-design problems are easy to deal with while others offer great obstacles, especially if viewed in terms of years. Thus, it was relatively easy to cope with cost factors such as transportability of a prefabricated structure, lifting and

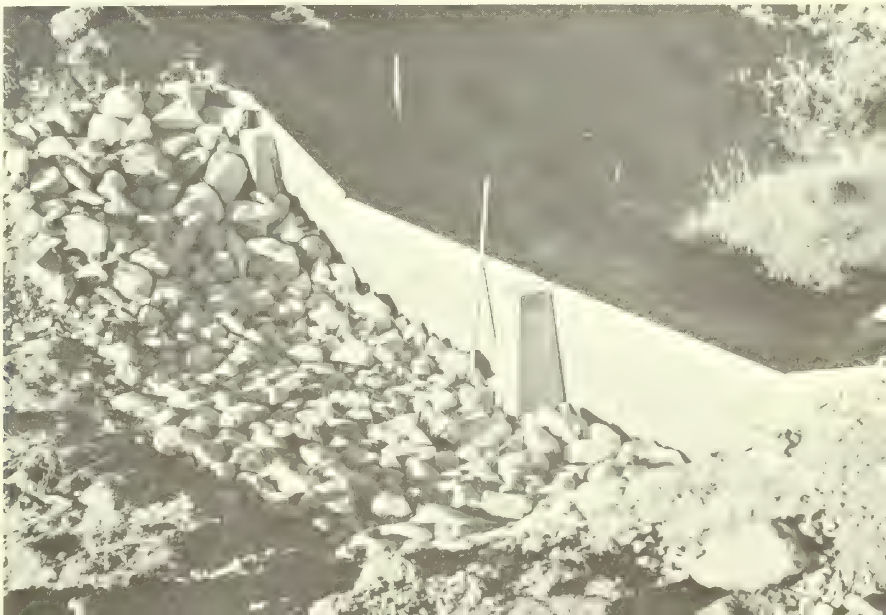

*Figure 1.--
Looking upstream on prefabricated check dam. Height of rod leaning against dam is 5.5 feet.*

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[2] *Prestressed Concrete of Colorado, Inc., Denver, helped in the design of the concrete elements. Mention of commercial enterprises is solely for necessary information; no endorsement by the U. S. Department of Agriculture is implied.*

placement of structural units, and number of individual units per check dam. It was decided that the prefabricated dam should be assembled in the field. that the individual unit should not weigh more than 2 tons, that one machine (backhoe) should be able to handle the units, and that the number of concrete units should be small.

But solving other cost-design problems, such as those connected with stability aspects and factors of safety, offers greater difficulties. Where life and property would be endangered by the failure of a structure, extensive effort to evaluate all site characteristics pertinent to the safe design of the structure are justified, and large safety margins in the design itself are conventional and proper. In general, structures designed for water storage entail some jeopardy to life and high-cost property. It is also true, in general, that their structural stability remains static, or deteriorates with age, so that the initial design must be adequate to withstand the full stresses of anticipated events indefinitely or over some specified life of the structure.

On the other hand, possible failure of gully control structures in wildlands does not usually jeopardize life or valuable property. Also, and very significantly, their design stability is augmented in time by the very nature of their function--that of trapping sediment to the point where the structure crest becomes a new level of the upstream gully floor. Thus an effectively designed and placed check dam should be exposed to the full magnitude of design stresses only during an initial period of time, and one so limited that there should be very low probability of an event with destructive potential.

These considerations have been incorporated into the design of the prototype check dam, and into the general recommendations for such structures. It is believed that they form a sound basis for a realistic design for check dams from the viewpoints of reliability and economics.

THE PROTOTYPE

A slab-buttress structure offers great advantages in the design and installation of a multipurpose check dam. Such a structure was designed of nine major parts: six 3-inch thick prestressed wall slabs, manufactured from conventional concrete, and three buttresses with footing, formed into one unit each from lightweight reinforced concrete (fig. 2). The use of lightweight aggregates saves one-third of the weight as compared with conventional concrete. The heaviest part of the structure (outside buttress) weighs 1.7 tons. Total weight of the dam is 9.8 tons. The overall length of the check dam is 45 feet; its effective height is 4 feet. Depth of freeboard is 2.5 feet.

Location

The prototype check dam was installed in July 1963 in the main gully of a watershed on the western slope of the Rocky Mountains about 40 miles southwest of Glenwood Springs, Colorado (fig. 3). The watershed area above the dam is approximately 1 square mile; elevation ranges from 7,500 to 8,500 feet. Soils are derived from shales and sandstones of the Wasatch formation. A tendency for subterranean erosion or "soil piping" is an outstanding characteristic of the alluvial soils of the main valley bottom. In selecting a site for the dam, a location was chosen where the soils did not "pipe." The vegetation consists mainly of Gambel oak, big sagebrush, Kentucky bluegrass, and western wheatgrass. Sagebrush occurs predominantly on the bottom lands and the south slopes. Gambel oak occupies ridges and the north slopes.

Records from 1961 to the present show that the area received an average total precipitation per water year (October 1 to September 30) of 16.5 inches. Compared with longer records from nearby stations, this amount appears to be close to normal. Gully flow is ephemeral, and occurs during spring snowmelt and exceptionally intense summer storms. The load of these flows consists mainly of fines and sand; gravel and boulders are present only occasionally. Flow was not measured before the dam was installed.

Placement

The check dam can be placed within 3 hours, not counting time for excavation and

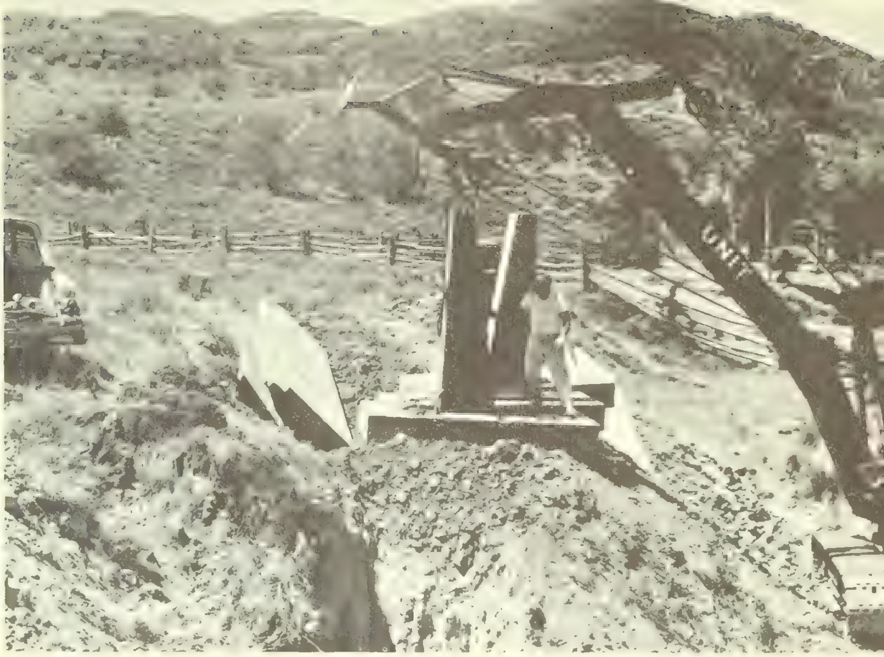

Figure 2.--
The units were placed on the gully bank to facilitate handling by the backhoe.

backfill. A backhoe (or a similar type of equipment) and only two laborers are required. The machine (1) excavates the foundation, (2) excavates the keys in the channel bottom and side slopes, (3) installs the units, and (4) backfills. Steel loops, attached to all concrete units during manufacture, facilitate their handling. No hole-to-hole fitting is required for the placement of the units. Buttresses can be alined horizontally by eye, but a hand or engineer's level should be used for the vertical alinement.

The upstream face of the buttresses is inclined to an angle of about 10 degrees with the vertical, and causes the wall to lean downstream. This inclination of the wall facilitates installation of the individual slabs, since gravity holds the slabs against the buttresses. The sloping wall also increases the stability of the dam by adding the weight of the water to the structure (see W_{W_2}, fig. 7). To prevent slippage at the base of the wall, the footing adjacent to the buttress is grooved (fig. 4). Steel plates and angle irons hold the upper wall and the freeboard slabs in place during the backfill operations, and add some stability to the dam wall.

INSTALLATION PROCEDURES

Construction plans are shown in figure 5, pp. 8-9. Step-by-step procedures are:

Figure 3.--
Note that the channel side slope was disturbed as little as possible during excavation for the key and buttresses.

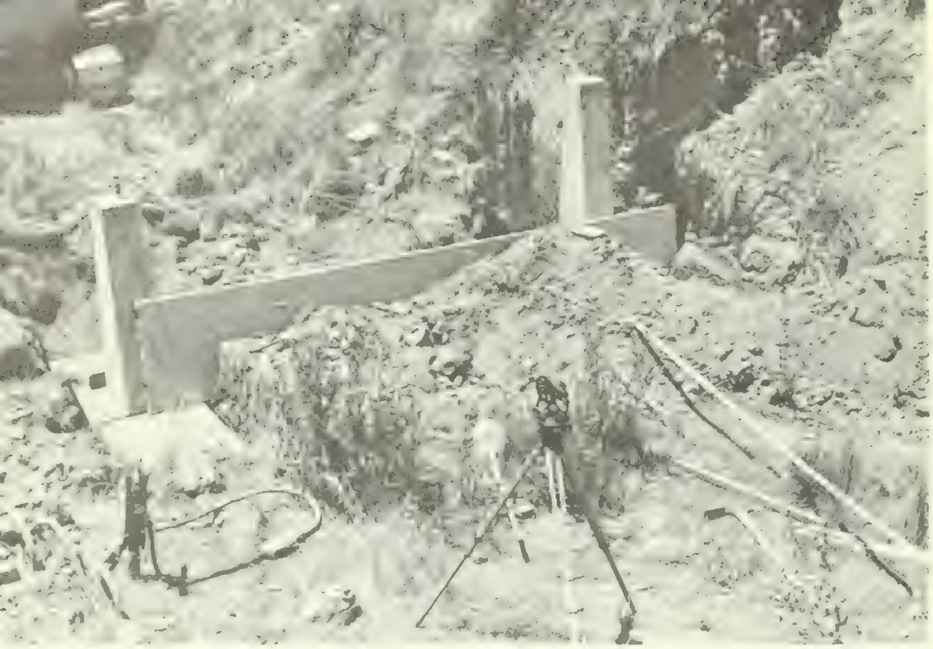

Figure 4.--
The first wall slab is set into a groove in the footing on the upstream side of the buttresses.

1. Excavate for keys and foundation slabs. Place all structural parts on the gully bank.
2. Install one outside buttress and the center buttress. Set a bottom wall slab against these buttresses so that one end of the slab touches the bolts protruding on the upstream face of the center buttress.
3. Place the second outside buttress (use the first bottom wall slab to align this buttress). Install the second bottom wall slab in the same manner as the first. With hammer and chisel, provide grooves on the upper side of the bottom wall slabs to accommodate a 3/8-inch bolt (spacing indicated in fig. 5). Attach two steel plates each to all bolts and tighten nuts loosely.
4. Place the next two wall slabs.
5. Fasten steel plate on the bolts of the center buttress and tighten nuts on all other bolts. Make grooves on the upper side of the dam wall for the accommodation of 3/8- and 5/8-inch bolts, respectively.
6. Loosely fasten angle irons and steel plates to the bolts.
7. Place freeboard slabs on the dam wall between the angle irons and steel plates (fig. 6).
8. Tighten all loose nuts.
9. Drive at least two steel posts into the ground behind the downstream side of the foundation slabs if on bedrock foundation.
10. Backfill structure in layers. Compact each layer before the next is applied with machine operated compactor if possible.
11. Excavate for the installation of apron and bank protection device below the dam. Deposit excess material upstream from the dam.
12. Install apron and bank protection work below the dam with a length not shorter than 1.5 times the effective dam height.

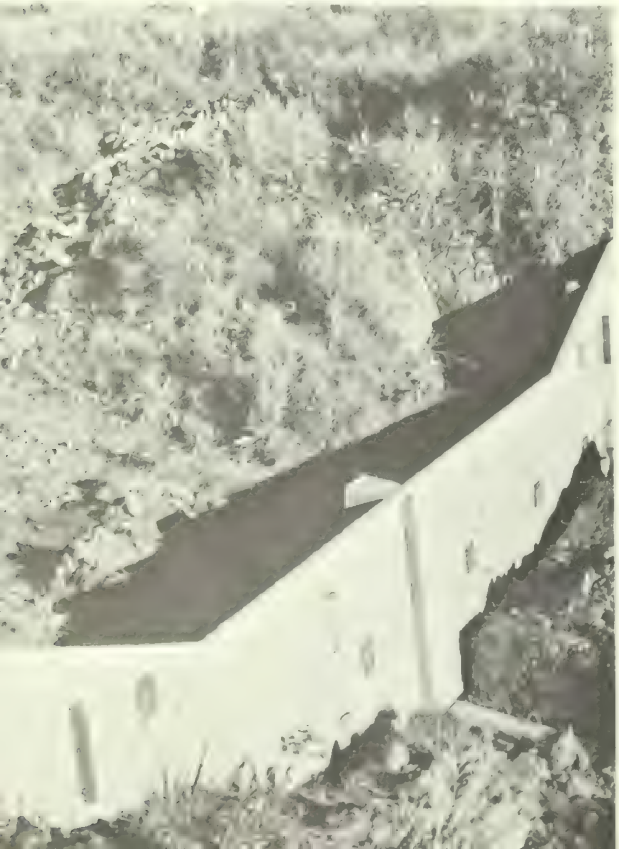

Figure 6.--
Looking at the upstream face of the completed dam before it is backfilled.

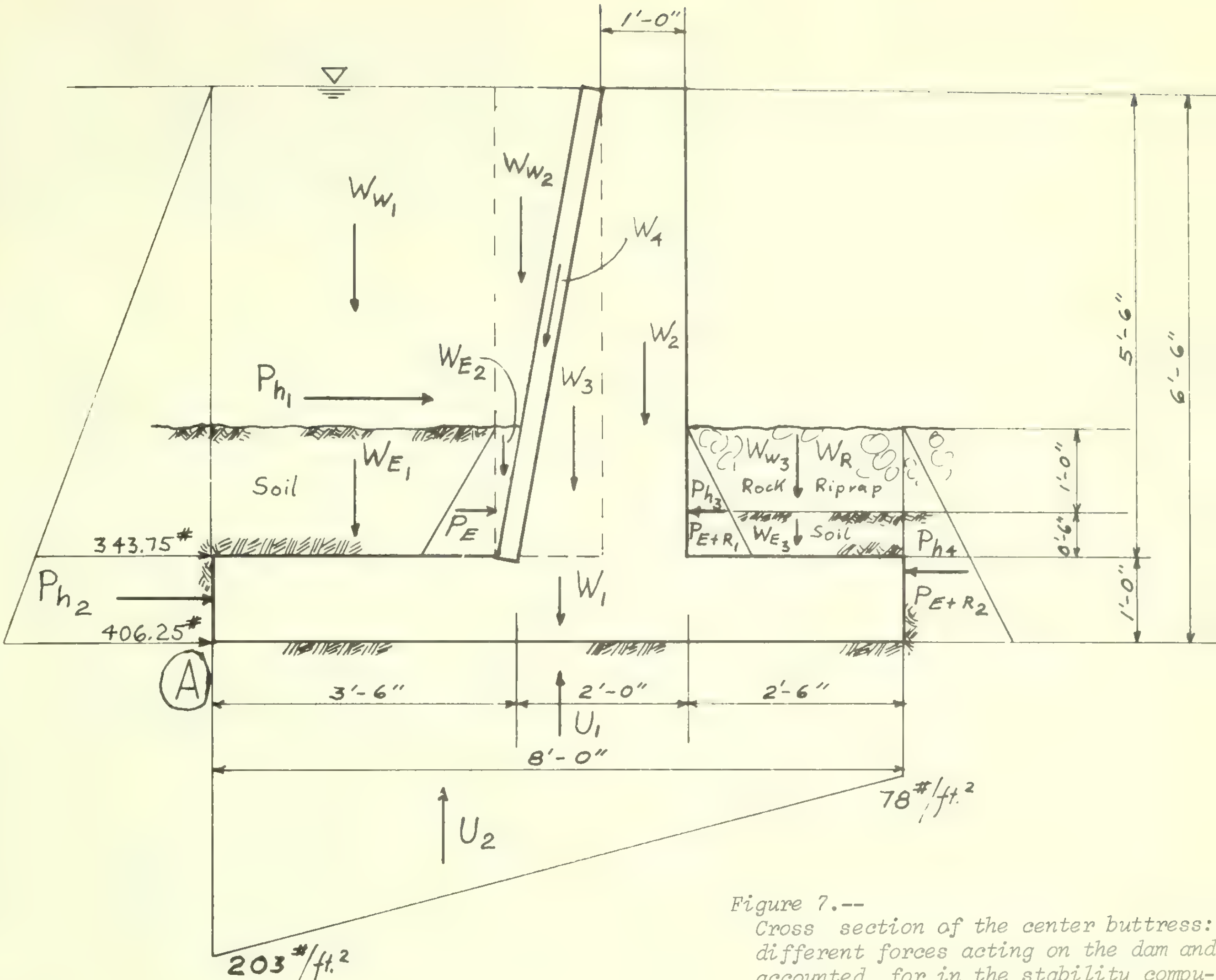

Figure 7.--
Cross section of the center buttress: different forces acting on the dam and accounted for in the stability computations are illustrated. The symbols in the drawing are explained below.

W_1, W_2, W_3 = *Weight of components of buttress.*
W_4 = *Weight of wall.*
W_W = *Weight of water.*
W_E = *Buoyant weight of earth.*
W_R = *Buoyant weight of rock riprap.*
P_{h_1}, P_{h_3} = *Hydrostatic force against wall.*
P_{h_2} = *Hydrostatic force against footing of buttress.*
P_{h_4} = *Hydrostatic force against buttress.*
P_E = *Active soil force on upstream face of wall.*
$P_{E + R_1}$ = *Passive force of soil and riprap on downstream face of wall.*
$P_{E + R_2}$ = *Passive force of soil and riprap on downstream face of buttress.*
U_1, U_2 = *Components of uplift.*

DISCUSSION AND APPLICATION

Stability Computations

Stability computations on the prototype (see appendix, p.14) considered overturning, foundation pressure, and sliding. Since the outside buttresses of the structure are partially embedded in the channel side slopes, these computations are based on the conditions at the center buttress. The design of the individual components of the structure is beyond the scope of this paper.

Overturning and Foundation Pressure

Figure 7 presents schematically the different forces acting on the center buttress and dam wall that were used in the stability calculations.

The following vertical forces and their moments about A were computed: dry weight of the components of the check dam; weight of the water acting on the dam; buoyant weight of the soil placed on the upstream and downstream buttress footing; buoyant weight of the rock riprap located on the downstream footing of the buttress; and uplift.

Since uplift was accounted for by assuming 50 percent saturation of the foundation by water, the dry weight of the structural components was used. The applied uplift factor of 0.50 is believed to be rather high for the particular location of the check dam, but if evaluated in the light of a complete gully treatment, the factor appears to be realistic.

It was assumed that the soils on both sides of the dam and the rock riprap would be fully saturated by water. Buoyant weights were therefore used. The buoyant weights were calculated by subtracting the weight of water from the estimated weight of the materials.

The following horizontal forces and their moments about A were considered: (1) the hydrostatic head of the water upstream and downstream from the dam; (2) the active soil pressure on the upstream face of the dam wall; and (3) the passive pressure of the soil and rock riprap against the downstream side of the dam.

The hydrostatic head upstream from the dam was taken at 6.5 feet. This represents a safety margin in the stability computations, since the actual hydrostatic head decreases considerably at the lower 2.5 feet where open channel flow does not exist.

The center buttress was estimated to take half of the load acting on the wall between the outside buttresses. In the computation of this load, the bottom wall slab was used. This slab is cantilevered beyond the outside buttress for 5.5 feet (see appendix, p.15). The calculations of the hydrostatic force, acting against the footing of the center buttress (P_{h_2}, fig. 7), were simplified by assuming a rectangular force diagram.

Based on the expected magnitude of flow and the steep channel gradient (6 percent), it was assumed that tail water will not occur at the structure, and the hydrostatic head on the downstream side of the dam is given by the saturation water. The resultant force was calculated by the Rankine formula based on active and passive pressures of soil and riprap:

$$P_E = \frac{h^2 \times \gamma b}{2} \tan^2 (45^\circ \pm \frac{\theta}{2})$$

where P_E is the active or passive soil force on the upstream or downstream face of the dam, respectively (the "plus" sign denotes the equation for the passive and the "minus" sign the equation for the active pressure), h the depth of the material, γb the buoyant weight of the material, and θ the angle of repose. To simplify the calculations, one angle of repose for both soil and riprap was assumed.

The location of the resultant of the external forces was determined by dividing the sum of the moments about A of all vertical and horizontal forces by the sum of the vertical forces. The result shows that the resultant is located 6.09 feet to the right of A or 0.76 foot outside of the middle third section of the structure. Because stability conditions usually improve with time at a check dam, the resultant will shift toward the center of the dam.

When the maximum foundation pressure is considered in the light of the allowable pressure, the present location of the resultant appears to be acceptable. The pressure at the base of the structure was computed as follows:

$$q = \frac{\sum V}{BL} (1 \pm \frac{6e}{L})$$

where q is the pressure at base, $\sum V$ the sum of all vertical forces acting on the dam, BL the area of the base of the structure, e the eccentricity denoting the distance between the midpoint of the structural base and the location of the resultant, L the length of the base, and the "plus" and "minus" sign the maximum or minimum pressure, respectively. The maximum foundation pressure was found to be 1,184 pounds per square foot--a fraction of the estimated allowable pressure of 20,000 pounds per square foot. The foundation material was a sandstone member of the Wasatch formation. This rock is horizontally jointed, has some vertical seams, and is very hard where not exposed to long weathering processes.

Sliding

The shear available at the base of the check dam was obtained by correcting the sum of all vertical forces with an estimated coefficient of friction. The value of this coefficient depends largely on the type of the foundation. A sliding factor of 1.2 was obtained when the available shear was divided by the sum of all horizontal forces. Ideally, the dam would not slide if the factor were 1. Yet, a safety margin is desirable. Conventionally, a sliding factor of 1.5 or larger is considered adequate for safety. In the light of general gully control aspects, the given sliding factor of the check dam is regarded as adequate.

Ways to Increase Safety Factors

When doubt exists about the bearing capacity of the foundation, the resultant should be shifted into the middle third section by a change in the design. A very undesirable foundation would be presented by swelling clays, for instance. Just a few proposals shall be made here; a multitude of measures would lead to increased stability. For example, an additional foot of riprap could be added to the apron of the dam to provide a total rock depth of 2 feet. This would raise the sliding factor to 1.83, and would place the resultant of the external forces 4.66 feet to the right of point A or well into the middle third of the structure. Similar effects could be obtained by shortening the distance between the buttresses. Safety factors on stability could also be increased by changing part of the structure such as the connection of a key to the footing of the buttresses. The key would increase the vertical forces (acting against sliding) and it would decrease the uplift forces (again benefiting the forces against overturning and sliding). The use of conventional concrete in the buttresses, the placement of weep holes into the buttress footings, or enlargement of the footings would be other possible measures. One may also consider placing the structure on interlocking steel sheet piling or any other type of cutoff wall. To obtain greatest benefit, the piling should be watertight.

Keying the Structure to Gully Side Slopes

The main critical locations on the prefabricated check dam exist where the ends of the wall are buried in the banks, usually called the keys of the structure in the channel side slopes. Movement of the water around the ends of the wall, determined primarily by the head of water, the permeability of the soils, and the length of the keys, may lead to piping if the fines are washed out of the bank material. Investigations on older check dams have shown, however, that, in ephemeral streams, the stability of the keys is mainly endangered by the scouring action of the water on the downstream side.[3] Here, the direct impact from the waterfall or the development of eddies may cut the bank, with resultant loss of key and structure, if it is not adequately protected. Failures of check dams by piping were not recorded. These findings are not surprising. Depositions that occur with time on the gully bottom and banks above the check dam have a sealing effect, lengthen the route of the seepage water, and thus counteract the seepage forces. In contrast, on the downstream side of the dam, the water flow overtopping the structure gnaws on the channel side slopes. Therefore, an efficient protection of the side slopes below a check dam is more important for structural stability than the length of the keys.

Rock riprap, if used correctly, effectively protects gully side slopes. It provides extreme surface roughness to dissipate the energy of the falling water, and has a tendency to close larger voids that may occur. Along with other factors, gradation and angularity of the rock are very important for efficient use of riprap.

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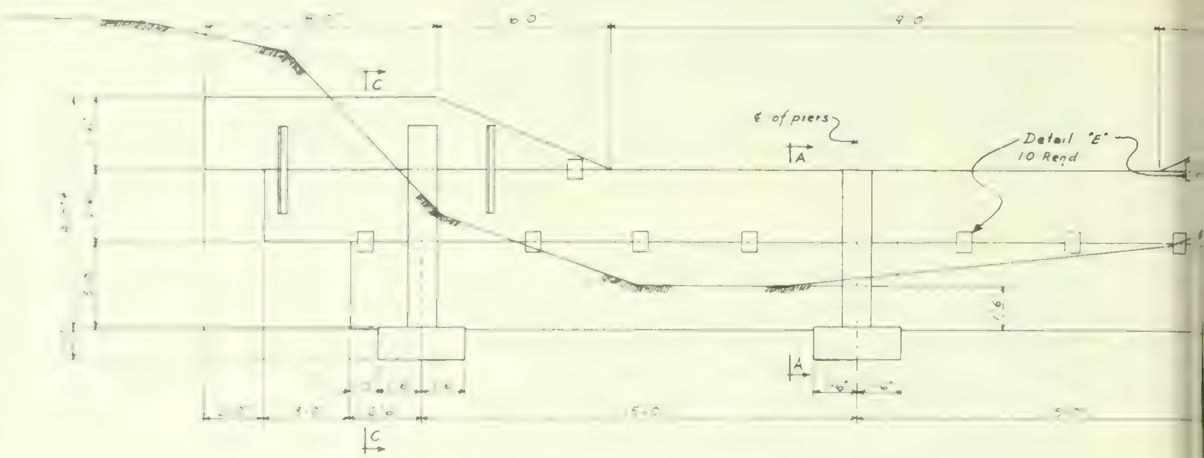
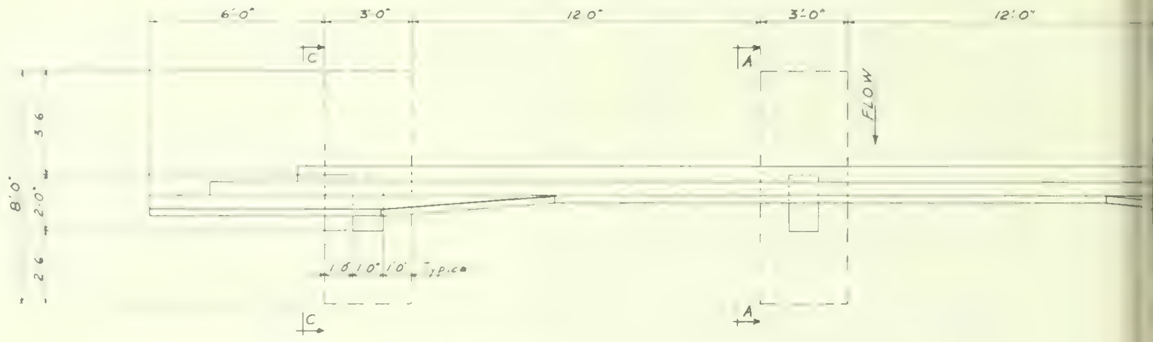
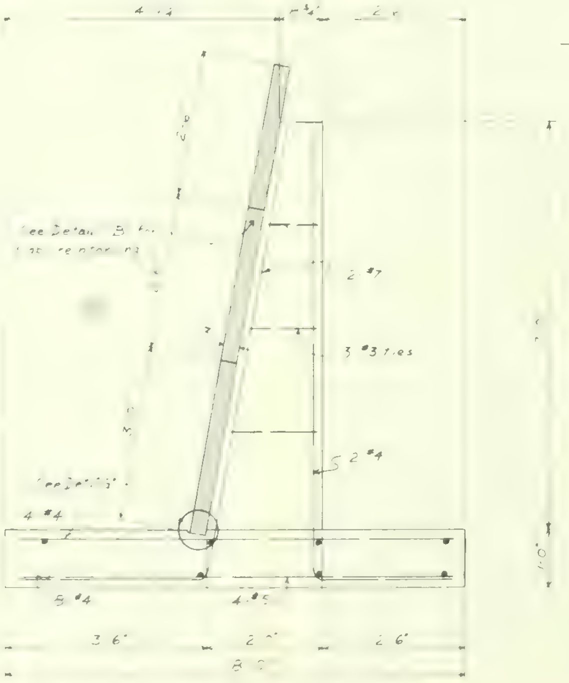
[3] *Heede, Burchard H. A study of early gully-control structures in the Colorado Front Range. U. S. Forest Serv. Rocky Mountain Forest and Range Expt. Sta., Sta. Paper 55, 42 pp., illus. 1960.*



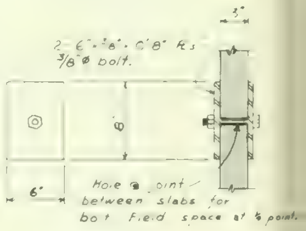
ELEVATION



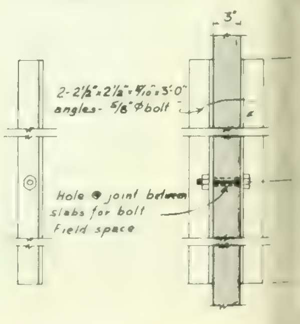
PLAN



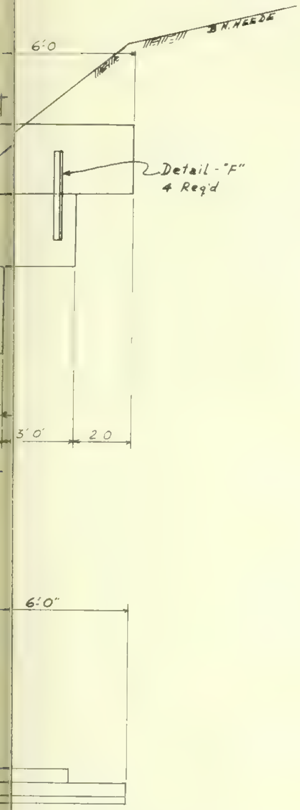
SECTION "C" AS SHOWN
SECTION "D" OPPOSITE HAND

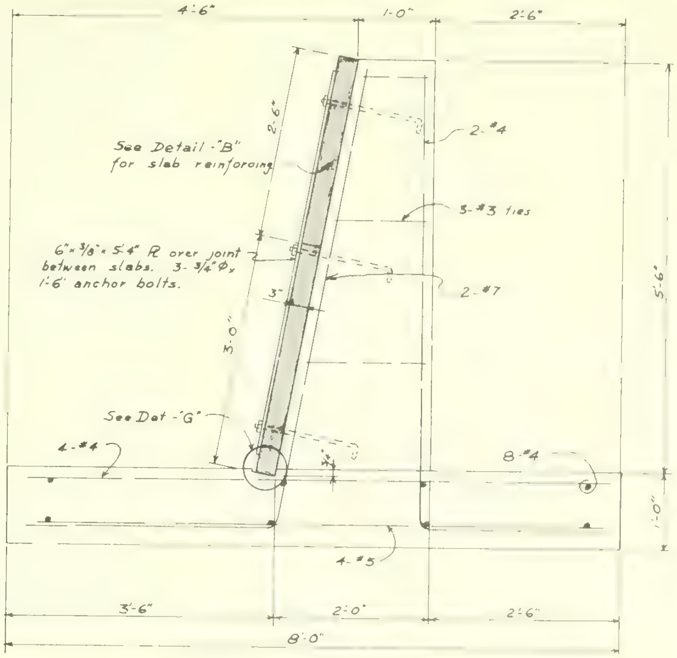

3"
2-6"x6"x0'8" Rs
3/8"ø bolt.
8"
6"
Hole @ joint between slabs for bolt Field space at ¼ points.

DETAIL "E"

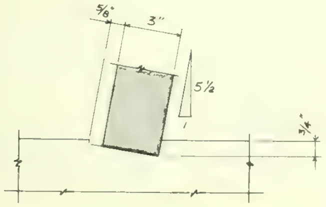

3"
2-2½"x2½"x5/16"x3'-0" angles- 5/8"ø bolt
Hole @ joint between slabs for bolt Field space

DETAIL "F"

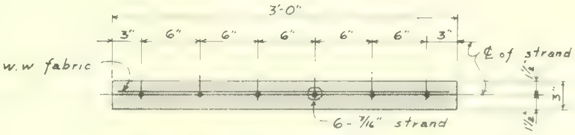




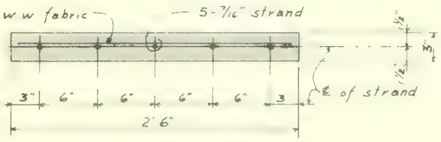
SECTION "A"



DETAIL "G"



3'-0" SLABS



2'-6" SLABS

DETAIL "B"

Figure 5.--
Detailed plan for concrete check dam.

Well-graded rock prevents the occurrence of larger openings in the riprap during placement, and angularity of the material provides an anchorage between the individual rocks. Large openings in the riprap should be eliminated under all circumstances, otherwise wave actions may attack the underlying bank material and remove it.

Seepage pressure and the safety of the keys against piping can be analyzed by the flow net method. To yield meaningful results, this method should be applied by designers with considerable experience in the field of soil mechanics. In general gully control work, such computations do not appear to be justified. Characteristics of soils vary greatly over short distances along the banks of alluvial streams. To obtain the data needed for the computation, extensive field sampling and office work would be required that are out of proportion to the size of the structures involved.

Our experience indicates that a key length of 4 feet in clayey soils and 6 feet in sandy soils is adequate (see fig. 3), but a final decision on these values should be made after site inspection.

If the dam will be installed in a sand bed, selected material should be used for backfilling on the upstream side of the structure. Clayey soils would best fulfill the purpose to lengthen the seepage route of the water around the structure.

Textbooks on soil mechanics give values for the coefficient of permeability, k, of broad soil classification groups. These table values can be used as a general guide to the order of magnitude of the permeability of a given soil. If, for instance, a porous soil is indicated, perhaps when k exceeds 100 feet per year, supplemental measures may be required. An effective device to prevent fines from washing out from around the keys is the reverse filter. Such a filter is established by placing materials, graded from sand to fine gravel, underneath the rock riprap on the channel side slopes.

Other measures exist to counteract seepage where it may create serious problems. The application of swelling clays or cement grout to the channel side slopes upstream from the dam has the same effect as the beneficial natural silting processes expected to take place with time.

While installing the keys of the check dam, there should be minimum disturbance of adjacent channel side slopes because previous sorting of surface materials has clogged many of the voids in these slopes. Destruction of this natural arrangement will increase the vulnerability of the banks to erosion until a certain quasi-equilibrium between a given flow and the side slopes is established again.

On our study area, certain soils seem to exhibit a pronounced tendency for "soil piping." Since little is known about the mechanics and the origin of this type of subterranean erosion, no remedy to this phenomenon can be given. It is advisable to avoid locations where soils appear to be susceptible to this erosion.

Suitability for Mass Application

The given design of the check dam is applicable to gullies of different widths without any change, but the maximum spacing between buttresses should not exceed 15 feet. The length of the individual wall slabs can easily be adjusted without increasing costs, since prestressed slabs are usually formed in beds several hundred feet long. Length of slab will be restricted only by aspects of transportability and weight. The application of several different widths of slabs will increase costs, however, since each width requires a separate bed. In the design of the prototype, only two widths, 2.5 and 3 feet, were used.

Any increase in the effective height of the check dam necessitates redesign. The stability computations on the prototype indicate that an increase in the height of the center buttress without other changes in the design may place the resultant overturning force into a position that would make the dam unsafe. The design may be altered as shown before.

From the discussion, it follows that a mass fabrication on the basis of the prototype design is feasible if the conditions of the individual treatment locations in the gully are considered. Mass fabrication is highly desirable. It is estimated that the manufacture of 15 or more of the prototype dams would cost $1,000 each.

The geometry of gullies usually varies greatly over short distances. These variations in gully dimensions may allow the selection of locations that not only satisfy the requirements for the placement of the dams as dictated by structural spacing or foundation conditions, but may also be suitable to a dam with a given design.

The design of the prototype has been satisfactorily tested for mass application in a treatment plan for a gully more than three-fourths of a mile long. At the proposed structural sites, the depth of the gully ranges from approximately 12 to 28 feet and the width from about 25 to 40 feet.

Applicability to Weirs

The design of the check dam is also applicable to different types of weirs. In fact, it appears to be advantageous to use prefabricated concrete units in weir construction because of the cost savings. Forming cutoff walls and pouring concrete in the field are time consuming and expensive. If the design is used for stream gages, however, the requirements for the factors of safety against overturning and sliding should be increased. Alterations should be made, as discussed previously, to shift the resultant force against overturning into the middle third section of the dam, and to raise the sliding factor to 1.5. It will always be desirable to place the structure on some type of a cutoff wall such as steel piling, concrete blocks or slabs if a bedrock foundation does not exist.

The prototype represents a trapezoidal broad-crested weir. The spillway could have other shapes or be fitted with a sharp-crested weir blade. If a center buttress is required, the height of this buttress should be lowered and the top slanted to assure free flow over the weir.

Seepage is undesirable for stream gaging. Products such as swelling clays and gunite may be used to close voids between the structure and the bedrock. To eliminate or decrease the magnitude of the cracks between the individual wall slabs, it may be advisable to manufacture the wall in one or two units only.

The weight of a stream gage wall, consisting of one or two units, can be illustrated by the prototype: its wall is 45 feet long at its maximum extension, 5.5 feet high at spillway elevation, and weighs 4.8 tons. If lightweight aggregates were used, this wall would weigh 3.2 tons, or each half 1.6 tons.

RESULTS

The ideas on the design and construction of the check dam, expressed earlier, were tested during the flows from spring snowmelt and found to work.

In April 1964, the peak flow of the melt season occurred with a head of 0.42 foot over the spillway of the dam. This head was estimated roughly to correspond to a discharge of 20 c.f.s. Depth-integrated samples of suspended sediment, taken from the stream near dam site, showed a concentration of 21,000 p.p.m. Gravel and boulders were present only occasionally in the total sediment load of the flow. The load consisted mainly of fines and sands.

Shortly after the peak flow had passed, the catchment basin of the dam was filled with sediment deposits to the crest of the spillway (fig. 8). It was estimated that this sediment amounts to 4,000 cubic feet or 140 tons. Runoff continued for 5 weeks, keeping the sediment above the dam saturated.

Thus, the hydrostatic forces of the water and the saturated soil pressure of the deposits acted simultaneously on the dam, and the structure passed through the most severe test it will probably ever experience. Yet, no displacement of the structural units or erosion at the dam site took place. The dam, the gully side slope protection installed below the dam, and the apron withstood all forces. Maintenance will not be required during the coming season.

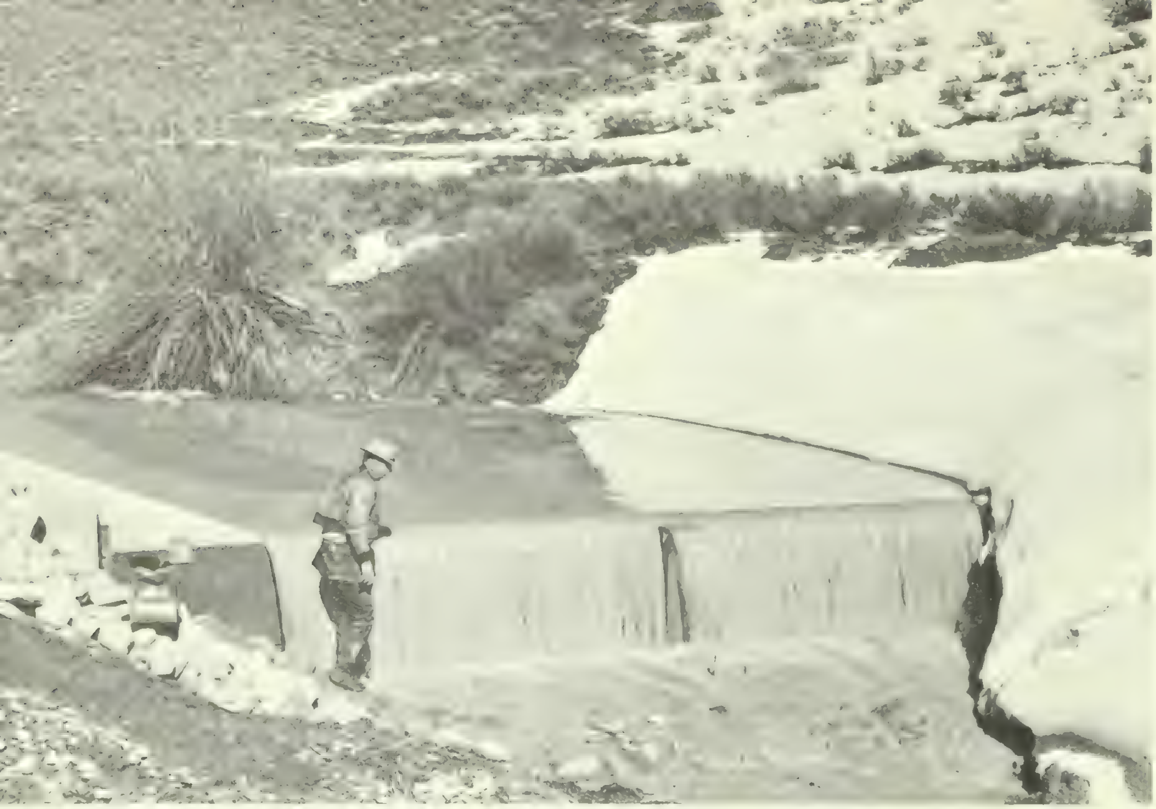


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Figure 8.--
Looking upstream on the prototype during the recession flow of the spring snowmelt. The head of the flow with reference to the crest of the spillway is 0.20 foot, as measured at the crest gage near the left margin on the figure. Sediment has filled the catchment basin of the dam to the crest of the spillway.

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APPENDIX

GENERAL DESIGN DATA AND ASSUMPTIONS

Weight of water = 62.5 lbs./cu. ft.

Dry weight of soil = 110 lbs./cu. ft.

Buoyant weight of soil = 47.5 lbs./cu. ft.

Dry weight of rock riprap = 125 lbs./cu. ft.

Buoyant weight of rock riprap = 62.5 lbs./cu. ft.

Weight of reinforced lightweight concrete = 100 lbs./cu. ft.

Weight of reinforced conventional concrete = 150 lbs./cu. ft.

Angle of repose of rock riprap = 35°

Angle of repose of soil (angle assumed at high value for convenience; true angle ranges between 27° and 30°.) = 35°

Coefficient of friction between dam and bedrock foundation = 0.80

Uplift factor (bedrock foundation seamy) = 0.50

Allowable foundation pressure (bedrock with seams) = 20 K/sq. ft.

NOMENCLATURE USED IN THE CALCULATIONS

B = Width of dam foundation.

$\sum H$ = Sum of all horizontal forces.

L = Length of dam foundation.

$\sum M_A$ = Moment of all external forces about point A.

$\sum M_a$ = Moment of all external forces about the outside buttress a.

P = Horizontal forces of water, soil, or soil and rock riprap.

R = Shear available along base (sum of all vertical forces corrected by coefficient of friction).

U = Uplift forces.

$\sum V$ = Sum of all vertical forces.

V_b = Vertical reaction from one side of the dam wall on the center buttress b.

W = Weight of water, soil, or rock riprap.

e = Eccentricity (horizontal distance between midpoint of structure and location of resultant of the vertical and horizontal forces).

f = Coefficient of friction between the dam and the foundation.

h = Head or depth of water upstream or downstream of the dam or depth of soil.

q_{max} = Maximum pressure of structure exerted on foundation.

γb = Unit buoyant weight of soil or soil and rock riprap.

θ = Angle of repose of soil and rock riprap.

STABILITY COMPUTATIONS

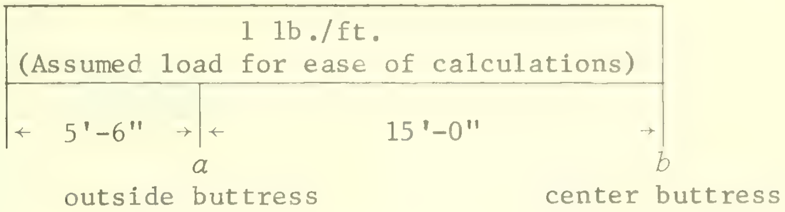
Overturning

Vertical Forces and Moments about *A*

Force × Arm = Moment	Force (lb.)	Arm (ft.)	Moment (ft.-lb.)
$W_1 = 3 \times 8 \times 100 =$	2,400	4.00	9,600
$W_2 = 1 \times 5.5 \times 100 =$	550	5.00	2,750
$W_3 = 1 \times \frac{5.5}{2} \times 100 =$	275	4.17	1.147
$W_4 = .25 \times 5.5 \times 15 \times 150 =$	3,094	3.875	11,989
$W_{W_1} = 3.25 \times 3 \times 5.5 \times 62.5 =$	3,352	1.625	5,447
$W_{W_2} = 1 \times \frac{5.5}{2} \times 15 \times 62.5 =$	2,578	3.58	9,229
$W_{W_3} = 1.5 \times 2.5 \times 3 \times 62.5 =$	703	6.75	4,745
$W_{E_1} = 3.25 \times 3 \times 1.5 \times 47.5 =$	695	1.625	1,129
$W_{E_2} = .27 \times \frac{1.5}{2} \times 15 \times 47.5 =$	144	3.34	481
$W_{E_3} = .5 \times 2.5 \times 3 \times 47.5 =$	178	6.75	1,201
$W_R = 1 \times 2.5 \times 3 \times 62.5 =$	469	6.75	3,166
$U_1 = -1\ (.50 \times 62.5 \times 2.5 \times 24) =$	-1,875	4.00	-7,500
$U_2 = -1 \left[\frac{(.50 \times 62.5 \times 6.5) - (.50 \times 62.5 \times 2.5)}{2} \times 24\right] =$	-1,500	2.67	-4,005
$\sum V =$	11,063	$\sum M_A =$	39,379

Horizontal Forces and Moments about *A*

Cantilever Reaction of Wall



$$\sum M_a = 1 \times \frac{15^2}{2} - 1 \times \frac{5.5^2}{2} - V_b \times 15 = 0$$

$$V_b = \frac{1 \times 15^2}{15 \times 2} - \frac{1 \times 5.5^2}{15 \times 2} = 6.49 \text{ lb./ft.}$$

Active Soil Pressure on Wall

$$\frac{h^2 \times \gamma b}{2} \tan^2 \left(45° - \frac{\theta}{2}\right) = \frac{1.5^2 \times 47.5}{2} \tan^2 (45° - 17.5°) = 14 \text{ lb./ft.}$$

Force × Arm = Moment

		Force (lb.)	Arm (ft.)	Moment (ft.-lb.)
P_{h_1}	$= 6.49 \times 2 \times 62.5 \times 5.5 \times \frac{5.5}{2}$	= 12,270	2.83	34,724
P_E	$= 6.49 \times 2 \times 14 \times 1.5 \times \frac{1.5}{2}$	= 204	1.50	306
P_{h_2}	$= \left(\frac{62.5 \times 5.5 + 62.5 \times 6.5}{2}\right) \times 3$	= 1,125	0.50	562
P_{h_3}	$= -1 \left(62.5 \times 1.5 \times \frac{1.5}{2} \times 12\right)$	= - 844	1.50	-1,266
P_{h_4}	$= -1 \left(62.5 \times 2.5 \times \frac{2.5}{2} \times 3\right)$	= - 586	.83	- 486
$P_{E + R_1}$	$= -1 \left[\left(\frac{47.5 \times .5 + 62.5 \times 1}{1.5}\right) \times \frac{1.5^2}{2} \times \tan^2 \left(45° + \frac{35°}{2}\right) \times 12\right]$	= -2,864	1.50	-4,296
$P_{E + R_2}$	$= -1 \left[\left(\frac{47.5 \times 1.5 + 62.5 \times 1}{2.5}\right) \times \frac{2.5^2}{2} \times \tan^2 \left(45° + \frac{35°}{2}\right) \times 3\right]$	= -1,851	.83	-1,536
		$\sum H =$ 7,454		$\sum M_A =$ 28,008

Sum of moments about A of vertical and horizontal forces:

39,379 ft.-lb. + 28,008 ft.-lb. = 67,387 ft.-lb.

Location of Resultant

$\frac{67,387}{11,063} = 6.09$ feet to the right of point A, then $e = 6.09 - \frac{8}{2} = 2.09 > \frac{8}{6}$

Pressure at Base

$$
\begin{aligned}
q &= \frac{\sum V}{BL}\left(1 \pm \frac{6e}{L}\right) \\
&= \frac{11,063}{8 \times 3}\left(1 \pm \frac{6 \times 2.09}{8}\right) \\
&= 461 \pm 723 \\
q_{max} &= 1,184 \text{ lb./ft.}^2
\end{aligned}
$$

Sliding

$R = \sum V \times f = 11.063$ lb. × 0.80 = 8,850 lb.

$\sum H = 7,454$ lb.

$\frac{R}{\sum H} = \frac{8,850}{7,454} = 1.19$

Heede, Burchard H.
1965. Multipurpose prefabricated concrete check dam. U. S.
Forest Serv. Res. Paper RM-12, 16 pp., illus.
Rocky Mountain Forest and Range Experiment Station,
Fort Collins, Colorado.

The dam consists of nine major parts: six prestressed wall slabs of conventional concrete, and three buttress-footing units of lightweight reinforced concrete. It can be placed in 3 hours (except for excavation and backfill) with two laborers and a backhoe.

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Research Paper RM-13

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The Beaver Creek Pilot Watershed for Evaluating Multiple-Use Effects of Watershed Treatments

David P. Worley

ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Fort Collins, Colorado Raymond Price, Director
FOREST SERVICE U. S. DEPARTMENT OF AGRICULTURE

U. S. Forest Service Research Paper RM-13 June 1965

THE BEAVER CREEK PILOT WATERSHED[1] FOR EVALUATING MULTIPLE-USE EFFECTS OF WATERSHED TREATMENTS

by

David P. Worley, Principal Economist

Rocky Mountain Forest and Range Experiment Station[2]

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[1] A 275,000-acre watershed on the Coconino National Forest in northern Arizona where costs and benefits of intensive multiple use land management are being evaluated as a part of the Arizona Watershed Program.

[2] Central headquarters maintained in cooperation with Colorado State University at Fort Collins; research reported here was conducted at Flagstaff, in cooperation with Arizona State College.

The Beaver Creek Pilot Watershed
for Evaluating
Multiple Use Effects of Watershed Treatments

David P. Worley

INTRODUCTION

Water supply problems are serious in many places in the semiarid Southwest. The economic development of many communities may be curtailed by insufficient water for agriculture, industry, and home use. One possibility to increase streamflow is to change the vegetative cover on upstream watersheds.

Before attempting such practices, the effects of these treatments on other watershed values, that is, timber, forage, wildlife, and recreation, must be determined. Also, if such practices are feasible, operational techniques must be developed. These can be done on a small scale by applying treatments on pilot watersheds where detailed records of products and costs are kept. Evaluating the benefits of a large-scale program requires, in addition, the collection of economic data about the particular river basins where such a program is contemplated. The pilot plant then provides a physical basis for evaluation, while the river basin studies provide an economic basis. Both must be harmonized to make the complete evaluation.

The Beaver Creek Pilot watershed (fig. 1) was set up to try watershed management techniques to increase streamflow. This paper describes the study to date. Summaries of the production of different products as a result of past and present management are presented. Product yields are combined in a "product mix" table, which shows the present multiple-use picture for each of three vegetation types. The table provides a benchmark for later comparisons with product mixes resulting from different watershed management treatments. The process for extending physical data from pilot plant to management unit is also discussed.

THE BEAVER CREEK PILOT WATERSHED

The watershed area, 275,000 acres, contains four different vegetation types; each type has a different streamflow potential. Only the three types containing trees are being considered for watershed treatments.

The whole watershed is divided into smaller pilot watersheds (fig. 1). The smaller watersheds will be treated first with a single treatment prescription. In the juniper types, converting the juniper tree overstory to grass, herbs, and shrubs is contemplated. Pine-covered watersheds will receive several conversion and thinning treatments. The larger watersheds--Bar-M Canyon, Woods Canyon, Rattlesnake Canyon, and Dry Beaver Creek--will be used to test combinations of treatments found productive on the smaller watersheds. The objective is to find out how well results can be predicted when several treatments are applied to larger areas. Wet Beaver Creek and Red Tank Draw watersheds will be used to develop operational techniques and determine treatment costs when applied to project-sized areas.

SOME WATERSHED CHARACTERISTICS

The Beaver Creek watershed is generally characteristic of Arizona watersheds. For example, there are about 13 million acres of land in Arizona covered by juniper woodland types and 3 million acres covered by the ponderosa pine type. A pilot plant exhibits some local peculiarities, however, that are not present everywhere. A careful description of these helps to interpret Beaver Creek results.

Some information is now available about precipitation, soils, and watershed cover.

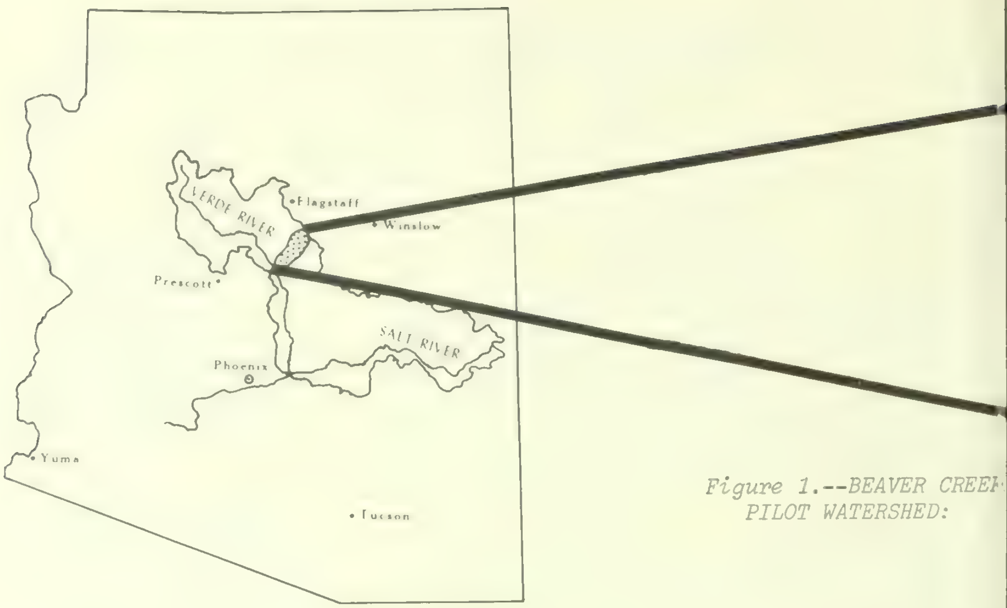
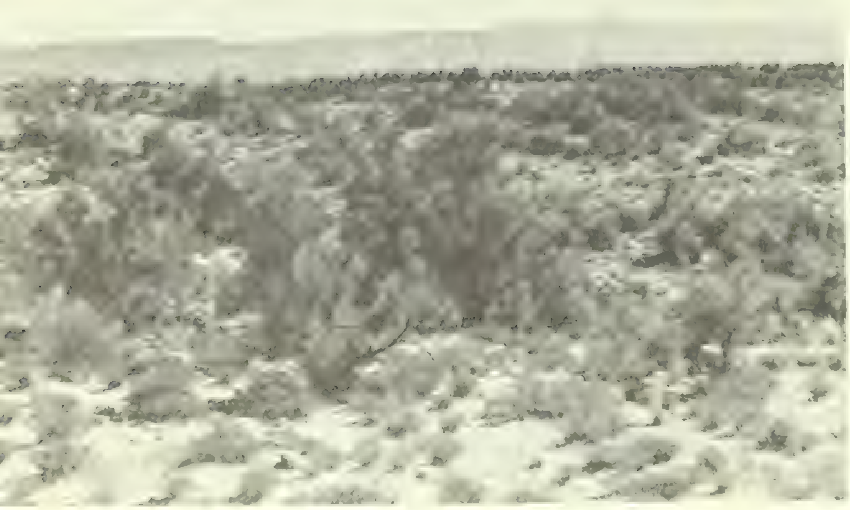


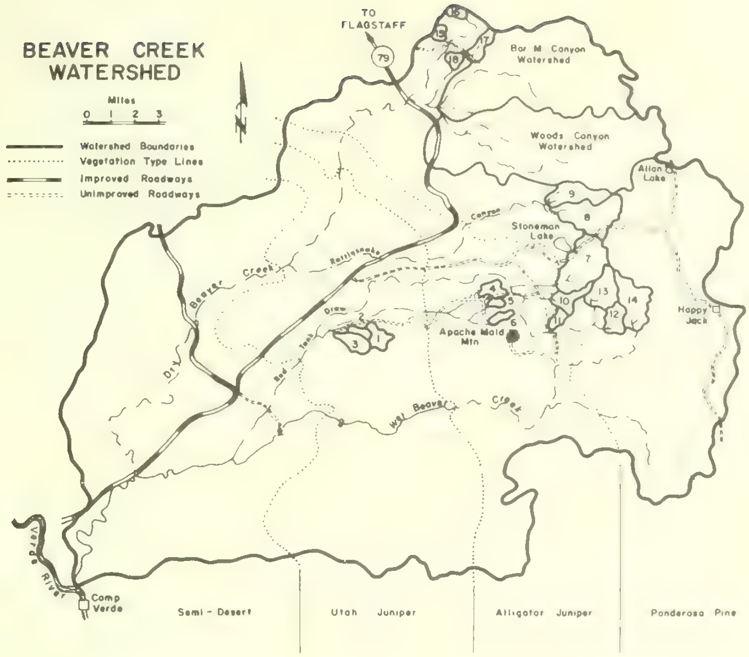
Figure 1.--BEAVER CREE
PILOT WATERSHED:



SEMIDESERT ZONE receives so littl rainfall that watershed managemen is not contemplated at this time.

ALLIGATOR JUNIPER (foreground) i sparse, appears on rolling topog raphy and is interspersed her with turbinella oak.

UTAH JUNIPER (background) occur on flat benches between deeply cu valleys. It is denser than it sister type.



PONDEROSA PINE occurs on rolling topography. Dense two-storied stands are interspersed with sienagas. Gambel oak is found singly or in copses with the pine.

These seem most important. Other characteristics will be considered as the data become available.

Precipitation

Precipitation is a major limiting factor affecting the amount, timing, and quality of the products produced on the watershed. The Beaver Creek precipitation-measuring network consists of 49 stations. The whole watershed area is covered generally, but gages are concentrated near the small subwatersheds to allow intensive analyses.

Summaries of storm, seasonal, and annual precipitation are made for the various watersheds. These data have been used to help explain streamflow characteristics. They will also be used to refine watershed calibration to speed up the treatment program.

Seasonal and annual range in precipitation amounts to about half the average (table 1). Differences between seasons in any one year are even greater. Seasonal and annual variations are closely associated with differences in product yields, which will be presented later.

Table 1.--Precipitation by vegetation type on Beaver Creek watersheds[1]

Months	Utah juniper		Alligator juniper		Ponderosa pine	
	1958	1959	1958	1959	1958	1959
	Inches					
October	1.49	1.40	2.21	1.00	2.54	0.91
November	3.49	1.61	4.95	1.86	6.43	2.34
December	.66	.03	.92	.05	1.04	.05
January	.38	.57	.43	.61	.58	.79
February	2.65	1.98	3.19	1.76	3.52	2.74
March	3.92	0	4.88	.06	5.81	.06
April	1.69	1.50	1.85	1.64	1.92	1.74
May	.51	.60	.76	.53	.62	.51
June	.10	.43	.34	.70	.87	.99
July	.24	1.86	.76	1.60	.53	1.75
August	2.06	2.99	4.28	3.19	4.27	4.50
September	6.04	.16	4.82	.01	5.74	.22
Total	23.23	13.13	29.39	13.01	33.87	16.60
Average[2]	18.56		20.98		24.85	

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[1] In 5 years of record, 1958-62, 1958 is the wettest year and 1959 the driest.

[2] Arithmetic average for the 5-year period, 1958-62.

Soils

Soils have as parent materials basalt, volcanic cinders, sandstone, and limestone.[3] Below 5,000 feet elevation sandstone and limestone predominate. Above 5,000 feet, in the area where watershed treatments are planned, the parent material is mostly basalt and cinders.

Basalt and cinders develop into heavy clay soils. Surface soils (down to about 3 inches in depth) are silty loams or clays. Subsurface soils are nearly all clays or silty clays. Structure is often massive with slow infiltration rates as soils become saturated. Many of the soils, particularly in the pinyon-juniper areas, are montmorillonitic clays. These clays characteristically shrink and swell in response to moisture changes, so that large cracks form during dry periods. These soils also tend to seal quickly as they become wet. Treatments that change plant cover may also change surface soil conditions, and could have a profound effect on the yields of all products.

Detailed soils analyses have been made for the various soils types. The range of soils encountered is relatively narrow (fig. 2). Special soils data were collected at each permanent installation for measuring range and timber products. Relations between soil and these products will be determined.

Watershed Tree Cover

Since tree cover is the characteristic that will be altered in the manipulation of vegetation on watersheds, it needs to be described carefully to: (1) determine treatment feasibility, (2) describe the treatment precisely once it is imposed, and (3) provide a basis for cost analysis. The ponderosa pine on watershed 12 was inventoried in detail to develop efficient methods of inventory.

The point-sampling system used to inventory the timber stands provided data for description of stand conditions based on three basal area stocking levels (25, 50, and 75 square feet per acre) so that the portion of a watershed not stocked, stocked, and overstocked with trees of different characteristics at these levels can be determined.

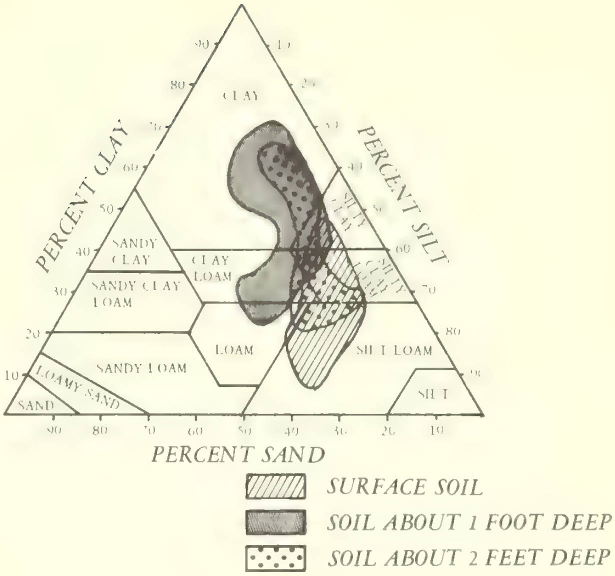

Figure 2.--Soil textures on the Beaver Creek Pilot Watersheds.

The importance of these data in describing pilot watershed characteristics can be shown by a brief example. Consider a proposition to thin the ponderosa pine to 50 square feet of basal area. Reference to table 2 shows that the treatment would only affect 68 percent of the area. It would not apply to the 16 percent already properly stocked or the 16 percent understocked. The desired stocking would exist on 84 percent of the watershed after treatment. From this and more complex statistics of the same sort, treatment feasibility can be judged. Since the point sample was made to cover the watershed, the treatment can be described precisely by reinventory, and the needed data for cost analysis are available.

WATERSHED PRODUCT HIGHLIGHTS

Streamflow

Potential streamflow changes are the criteria for the selection of watershed treat-

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[3] *U. S. Forest Service. Soil management report for Beaver Creek watershed of the Coconino National Forest, Region 3. 69 pp., illus. July 1960.*

Table 2.--Percentage of area stocked with trees to different basal-area levels, watershed 12

Basal-area level and stand condition	Ponderosa pine					Gambel oak	Alligator juniper	All species
	Saw-timber	Poles	Saplings	Reproduction	All size classes			
	- - - - - -	- - - - - -	- - - - - -	- - - - - -	Percent of area	- - - - - -	- - - - - -	- - - - - -
25 sq. ft. per acre:								
Properly stocked	38	21	13	13	9	15	14	5
Overstocked[1]	31	43	48	36	87	25	12	94
Not stocked	31	36	39	51	4	60	74	1
50 sq. ft. per acre:								
Properly stocked	28	23	16	16	16	17	10	13
Overstocked[1]	13	25	31	23	68	15	6	77
Not stocked	59	52	53	61	16	68	84	10
75 sq. ft. per acre:								
Properly stocked	20	23	16	16	14	16	8	17
Overstocked[1]	9	16	22	18	60	11	4	67
Not stocked	71	61	62	66	26	73	88	16

[1] Tally of two or more trees with one-tree expectation as a stocking criterion.

ments, and they form one basis for judging the success or failure of treatments. Each of the subwatersheds is stream gaged; a total of 24 gages are used. Eighteen of these are specially constructed flumes on small watersheds; the remaining six gage larger watersheds. Fourteen of the eighteen are designed to measure flow to 320 cubic feet per second (c.f.s.) and four measure flow to 120 c.f.s. Of the six larger watersheds, three are gaged over specially designed weir controls with capacities to 1,000 c.f.s. The other three are measured over mainly natural controls supported by only minimal artificial structures. Data from four of the larger stream gages are taken and summarized by the U. S. Geological Survey.

No record of underground flow is being made. It is believed that the treatments designed to increase streamflow will not significantly affect underground flow since there is little evidence of ground water flow in either the form of springs or in the streamflow hydrographs.

To decide if a treatment affects streamflow, pretreatment streamflow is gaged for several years on a watershed to characterize it in an untreated condition. Classically this is done through a calibration process in which the annual flow of one watershed is compared with that of another to predict streamflow of the watershed to be treated. Once this watershed is treated, streamflow departures from predicted streamflow attest to changes due to treatment. This process usually takes many years, since each year forms but a single observation. In this area of intermittent streamflow, however, it is possible to analyze flow periods instead of yearly totals. This modification is 1.7 times more efficient than yearly totals in the juniper types.

Another step is being taken to further reduce the calibration time to speed up the program. This is an analysis of recession and rising stages from which streamflow characterizations can be described mathematically for a watershed without using control watersheds. Posttreatment changes can then be calculated and summed for seasons or years.

The annual streamflow of the various cover types can be characterized from measurements of small untreated watersheds to show characteristics of importance to evaluation (table 3). The streamflow from these watersheds varies greatly between watersheds within types for any one year as well as between years. Variability between years follows precipitation patterns closely. Year-to-year variation is about as great as the average streamflow.

Table 3.--Average streamflow in inches[1] from several watersheds on Beaver Creek, by water year (October 1 - September 30) and tree cover type

Cover type and water year	Watersheds	Streamflow per unit area		
		High	Low	Average
	Number	- - - Inches - - -		
Utah juniper:				
1958	3	0.94	0.74	0.82
1959	3	0	0	0
1960	3	.62	.59	.61
1961	3	.28	.16	.21
1962	3	.18	.13	.16
Average		.40	.32	.36
Alligator juniper:				
1958	2	6.05	4.85	5.45
1959	3	.61	.06	.33
1960	3	5.07	3.19	3.91
1961	3	1.19	.44	.85
1962	3	6.00	3.62	5.09
Average		3.78	2.43	3.13
Ponderosa pine:				
1958	2	11.69	11.17	11.43
1959	4	1.04	.17	.42
1960	6	7.49	3.75	5.11
1961	6	2.39	.73	1.50
1962	6	9.05	4.94	6.67
Average		6.33	4.15	5.03

[1] Computed from preliminary area determination for individual watersheds.

Of particular importance is the great variability between watersheds in the same year. Within-year differences represent a greater proportional change in low streamflow years than in high streamflow years. In the pine and alligator juniper watersheds, the bulk of the flow is due to general winter storms, with snow accumulation forming a large part of the effective precipitation. These watersheds maintain consistent ranking in terms of their water yields. Utah juniper watersheds, on the other hand, depend upon local summer storms to a greater extent. The location of these storm centers plays a greater role in annual streamflow so that sometimes one watershed is ranked high and sometimes another. These facts point up the importance of carefully collecting and interpreting hydrologic data to account for these differences to improve predictions, and ultimately to suggest watershed characteristics that may be correlated with high yield to be looked for in other watershed areas.

Suspended Sediment

Suspended sediment samples have been collected from each flume at irregular intervals (table 4). They do not provide data from which total sediment yield can be estimated; rather they were intended to characterize amounts of suspended sediment at different levels of flow.

These data indicate that Utah juniper watersheds contribute far more suspended sediment during periods of streamflow than do the alligator juniper watersheds. Untreated pine watersheds appear to yield least of all. Thinning pine apparently did not produce major sediment increases, while pine-to-grass conversion caused tremendous but short-lived increases.

On a pine watershed during the winter of 1961-62, both bedload and suspended sediment yields were measured for extended periods of flow. About 350 pounds of sediment per square mile were measured for the winter flow; the mineral fraction was composed of 14 percent sand, 47 percent silt, and 39 percent clay (see fig. 2).

Timber Production

Timber production is being estimated on each watershed by a stand projection system.

Table 4.--Suspended sediment in parts per million (p.p.m.) determined from watersheds with different cover conditions, Beaver Creek watershed, 1957-62

Cover type	Samples taken	Maximum suspended sediment measured						Proportion of samples under 500 p.p.m.
		1957	1958	1959	1960	1961	1962	
	Number	p.p.m.						Percent
Utah juniper	20	--	6,600	--	3,200	17,400	--	47
Alligator juniper	60	3,000	630	4,500	2,200	120	330	83
Ponderosa pine	280	--	200	20	210	190	110	100
Thinned pine	40	130	480	--	180	320	100	100
Pine cover converted to grass cover	30	--	13,100	560	70	830	230	78

Growth is tabulated in total cubic feet of solid wood per acre per year by tree size and quality classes. Later this is converted to board-foot and cordwood growth.

A preliminary estimate of timber growth on the ponderosa pine portion of the watershed was made from 32 continuous inventory plots (part of the Coconino National Forest control system) on the Beaver Creek watersheds. They were first measured in 1950 and remeasured in 1961.

Data for watershed 12 (table 5), inventoried in the summer of 1962 are fairly typical of the type as a whole.

As different watersheds are treated, effects on the growth of different sizes and qualities of timber will be determined to give a physical background for judging the economic importance of the new timber production.

Herbage Production

Herbage production is estimated at 10 locations within each of the small watersheds (table 6). At each location is a cluster of 10 permanently located 9.6-square-foot plots. Herbage weights are estimated on five of these plots, and five are reserved for clipping to provide a basis for adjusting weight estimates. They provide a measure of the herbage produced by individual species at the particular locations each year. They are inadequate, however, for characterizing production on entire watersheds. Changes due to treatment are determined by periodic remeasurement.

Limited measurement of herbage production on treated areas, adjacent to untreated watersheds, suggests the following increases may result:

Cover type and treatment	Increases in Grass production	Total herbage
Utah juniper:		
Removed juniper	2 times	2-3 times
Alligator juniper:		
Removed juniper	None	1-1¼ times
Ponderosa pine:		
Converted to grass	4-5 times	4-5 times
Thinned to 80 sq. ft. basal area per acre	2-3 times	2-3 times

Increases are based on production estimates made during the first three to four posttreatment years.

Herbage production is low. The range of data suggests large proportional changes due

Table 5.--Annual volume and growth per acre of the timber overstory on watershed 12, measured first in 1950, remeasured in 1961, inventoried in 1962, Beaver Creek watershed

Species and size class	Volume			Growth		
	Cu. ft.	Bd. ft.	Cords	Cu. ft.	Bd. ft.	Cords
PONDEROSA PINE--						
Poles:						
Small (4-6 in. d.b.h.)	233	--	1.04	16.8	--	0.03
Large (8-10 in. d.b.h.)	212	--	2.37	6.1	--	.07
Sawtimber:						
Small (12-16 in. d.b.h.)	181	607	1.91	5.2	16.8	.06
Medium (18-22 in. d.b.h.)	314	1,456	--	.8	3.9	--
Large (24 in. and over d.b.h.)	299	1,673	--	4.6	23.8	--
Total	1,239	3,736	5.32	[1] 33.5	44.5	.16
OAK	198	--	3.72	3.5	--	.04
JUNIPER	109	--	--	.9	--	--
Total	1,546	3,736	9.04	37.9	44.5	.20

[1] Growth of pine determined with standard error of ± 2.1 cubic feet per acre per year.

to treatment, but the actual changes are small. Analysis by individual species indicates that their production is strongly affected by timing and amount of precipitation.

Steps are being taken to relate soils to forage production. The intent is to map overstory and soils characteristics on the watersheds to determine the proportion of the watershed in different soils-overstory classes. By noting these different soils-overstory classes and weighting them by the area mapped in these classes, an average production figure can be determined for the watershed. Plot-cluster records taken annually will serve to adjust for year-to-year variation.

Table 6.--Herbage produced on plots within untreated watersheds, by cover type Beaver Creek watershed

Cover type	Perennial grasses produced (3 years' record)		Total herbage produced (2 years' record)	
	Range	Average	Range	Average
	- - - Air-dry pounds per acre - - -			
Utah juniper	15- 30	20	200-210	205
Alligator juniper	130-240	190	370-540	450
Ponderosa pine	60-140	100	185-195	190

Wildlife and Recreation

Wildlife and wildlife recreation are being evaluated cooperatively with the Arizona Game and Fish Department. A system of permanent plots on which groups of pellets are counted periodically has been maintained since 1958 to estimate wildlife use of different areas. Deer use is estimated from the widely used average deer defecation rate of 13 groups per animal per day. On this basis, the estimated deer population has averaged seven per square mile for the entire Beaver Creek study area.

Year-to-year populations ranged from 4 to 14 deer per square mile during the period of record, 1958 to 1962. This fluctuation may be due to differences in weather conditions and to a declining herd during this period. Improved sampling techniques are now being used by the Arizona Game and Fish Department to determine the populations of elk and turkey.

Records of wildlife-based recreation are provided by cooperative hunter check stations and traffic counters. Statistics for 1961 and 1962 are as follows:

	1961	1962
Number of hunter vehicles	1,750	2,380
Hunter vehicles as a percent of the total	43.5	54.5
Average number of hunters per vehicle	2.3	1.8
Number of hunters	3,996	4,368
Total days afield	5,994	4,805
Average days afield	1.5	1.1
Deer killed	304	315
Hunter success percent	7.6	7.2
Acres per day afield for area covered (approx.)	25	30

A MULTIPLE USE PRODUCT MIX

To have a beginning point for a multiple use evaluation, a benchmark is needed from which to compare present products with those produced under new practices. It can be established by showing the pretreatment estimates of all the product yields in the form of a product mix table (table 7). A product mix table describes multiple use by spelling out the quantities of products that come from a particular area or class of land. Since all summaries in table 7 are based on less than

Table 7.--Beaver Creek product mix from untreated areas, 1958-62

Cover type	Average yield, by product							
	Water per acre	Forage-grass per acre		Timber per acre per year			Game	Hunter use
		Per year	Total					
	Inches	Pounds, air-dry		Ft.b.m.	Cords	Cu.ft.	Deer/sect.	Hunter days/sect.
Ponderosa pine	5.0	100	190	[1] 44.5	[1] 0.16	[1] 33.5	--	--
Alligator juniper	3.1	190	450	--	--	1-3	--	--
Utah juniper	.4	20	205	--	--	2-4	--	--
Combined types	--	--	--	--	--	--	7	20-25

[1] Watershed 12.

5 years of data, and some from restricted parts of the watershed, this first approximation is crude. The records will be refined and expanded to make future comparisons more precise as the project continues.

Comparison with posttreatment tables will show what is gained and sacrificed in multiple use terms for a redirection of management. Such comparisons form a physical basis for deciding from among alternative practices. For example, it may be decided to increase streamflow by a particular amount, and the pilot plant studies may suggest several ways to do this. A comparison of the product mixes for the several alternatives provides a basis for an appraisal of the advantages and disadvantages in physical product terms.

By comparing before-and-after product mixes, including posttreatment changes, generalizations can be quantified. In a heavy clearing treatment, for example, water, sediment, and forage can be expected to increase, while ultimately timber production will decrease. Game habitat will be affected adversely for some species and favorably for others. Most of the resultant product mixes will not be static, but will change from year to year as the land adjusts to treatment. In the short run, for example, greatly expanded timber harvests will increase economic activity, but finally it must assume a lower level.

FROM PILOT PLANT TO MANAGEMENT UNIT

As soon as posttreatment results become available from the pilot watersheds, they will be generally useful to land managers. Precise quantitative extensions of pilot plant results, however, will rest largely with research in the various technical fields. The pilot plant, then, is a vital link between research results and application. It becomes a proving ground to determine the utility of research results in a project-sized operation. It becomes a developmental laboratory for designing inventory techniques for measuring research variables in the field efficiently enough to be practical for management and precisely enough to lend practical meaning to research results. It points out gaps in knowledge that need to be filled so that recommended management practices can be translated into action.

The above requirements impose several tasks on the pilot watersheds as major responsibilities:

1. To describe the watershed characteristics in detail so that the pilot watershed limits are stated in terms that will harmonize with research work in the various fields. Watershed characteristics described earlier suggest some of the limits set by precipitation, soils, and tree overstory.

2. To develop efficient methods for inventorying independent factors required by research relations so that they can be used for predicting outcomes in larger management situations. Range research, for example, has indicated the relations between timber overstory and forage production. From records of overstory data on range plot clusters, this relation can be determined for Beaver Creek conditions to show the sampling design necessary to get acceptable results.

3. To suggest the needed additional research required to put the pilot tests on the ground and to interpret the results for evaluation. Often treatments that seem simple but are really loosely defined are difficult to put on the ground because of gaps in research knowledge.

   One example of this is control burning a ponderosa pine watershed. On the face of it this sounds simple. But pilot plant objectives and administrative prudence require asking the why, when, what, how, where questions, and it becomes apparent that really too little is known to make effective use of a watershed by just intentionally burning it. Thus a fire research project has been located near the pilot watersheds to provide background information about the use of fire on a pilot test basis. A decision to burn can then be defended on technical grounds, and adequate descriptive data can be collected from the pilot watershed about the fire and analyzed for interpretation and later extrapolation to other areas.

Another example involves interpretation of herbage production records so they will have meaning in an economic evaluation. Herbage becomes forage, and an economic reality, when it is consumed by livestock and game. Since watershed treatments are likely to increase forage quantities and change forage quality, their effects on meat production and animal gains become an important economic question. This question led to a separate study designed to determine the influence of tree overstory on forage and beef production, and the relation of the quality and quantity of forage eaten to animal weight gains. A similar study is anticipated by the Arizona Game and Fish Department to characterize treatments in terms of deer potential. These studies will help in the interpretation of watershed treatment effects on the range resource, and will point out the measurements that require special attention in inventories so efficient methods suitable for large-scale management can be developed.

The implication of the foregoing is that, as a result of the pilot plant operation, (1) questions are asked of research, (2) methods are developed for predicting watershed treatment outcomes, so that (3) before-and-after product mixes can be determined for other areas generally similar to the pilot plant. This will enable land managers to determine the product mix and economic data about their problem areas to help them decide the best treatment.

Agriculture --- CSU, Ft. Collins

Worley, David P.
1965. The Beaver Creek pilot watershed for evaluating multiple use effects of watershed treatments. U. S. Forest Serv. Res. Paper RM-13, 12 pp., illus. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Pilot watershed treatments to increase streamflow are being evaluated in central Arizona to determine multiple use effects on the major forest resources. Methods are being developed for predicting watershed treatment outcomes, so that before-and-after product mixes can be estimated for similar areas.

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U. S. Forest Service Research Paper RM-14 August 1965

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ROTATION, REST-ROTATION, AND SEASON-LONG GRAZING ON A MOUNTAIN RANGE IN WYOMING[1]

by

W. M. Johnson, Principal Plant Ecologist

Rocky Mountain Forest and Range Experiment Station[2]

U. S. DEPARTMENT OF AGRICULTURE

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[1] Comparisons reported were undertaken jointly with the Medicine Bow National Forest.

[2] Central headquarters maintained in cooperation with Colorado State University at Fort Collins; author is located at Laramie in cooperation with the University of Wyoming.

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Rotation, Rest-Rotation, and Season-Long Grazing on a Mountain Range in Wyoming

by

W. M. Johnson

One of the most important problems facing managers of cattle ranges in the western United States is how to obtain better distribution of grazing. On almost all cattle ranges there are certain areas where grazing is concentrated, while adjacent areas may be very lightly grazed. This is especially noticeable where the range is composed of moist bottom lands interspersed with drier uplands. Areas of concentrated grazing may also develop away from water. On these areas the preferred forage plants are heavily utilized, and less desirable plants are grazed very lightly, if at all. For this reason, it is sometimes difficult to improve range conditions even when numbers of livestock are in balance with forage production.

The Pole Mountain unit of the Medicine Bow National Forest in Wyoming is an example of a cattle range where these problems exist (fig. 1). Three allotments in this unit were selected for study: the North Pasture, Green Mountain, and Lodgepole. Previously, under season-long grazing (June 1 to October 15), cattle on the North Pasture Allotment grazed only about one-half of the usable range area. Some of this area, principally in the southwest quarter of the allotment, was grazed in excess of 50 percent utilization. The remainder was grazed very lightly, principally along the bottoms.

Green Mountain was an example of heavy grazing throughout the entire allotment, with the bottom areas grazed excessively. Topography, water distribution, and forage types were similar to the North Pasture Allotment. Except for scattered rock outcrops and occasional patches of dense timber, all portions of the allotments were easily accessible to livestock.

The bottom areas in the Lodgepole Allotment were all very heavily grazed, but some of the upland areas were grazed more moderately. Topography and forage types in the northeast quarter of this allotment were similar to the other two allotments, therefore observations were confined to this area.

The object of this study was to evaluate three methods of management in relation to their effect on patterns of utilization on upland and bottom areas, and accompanying changes in the vegetation.

Different methods of management were compared on the three allotments. The North Pasture Allotment was divided into four units about equal in grazing capacity for rest-rotation management. Three units were grazed each season, while the fourth was left ungrazed for that season. The period of use on each unit and the unit not grazed for each of the 4 years of the study were as follows:

	Year and Unit No.			
	1958	1959	1960	1961
June 1-July 16	1	2	3	4
July 17-Aug. 31	2	3	4	1
Sept. 1-Oct. 15	3	4	1	2
Not grazed	4	1	2	3

The Green Mountain Allotment was also divided into four units, but all units were grazed each year in a simple four-pasture rotation system. The time of grazing was rotated as follows:

	Year and Unit No.			
	1958	1959	1960	1961
June 1-July 4	2	3	4	1
July 5-Aug. 7	3	4	1	2
Aug. 8-Sept. 10	4	1	2	3
Sept. 11-Oct. 15	1	2	3	4

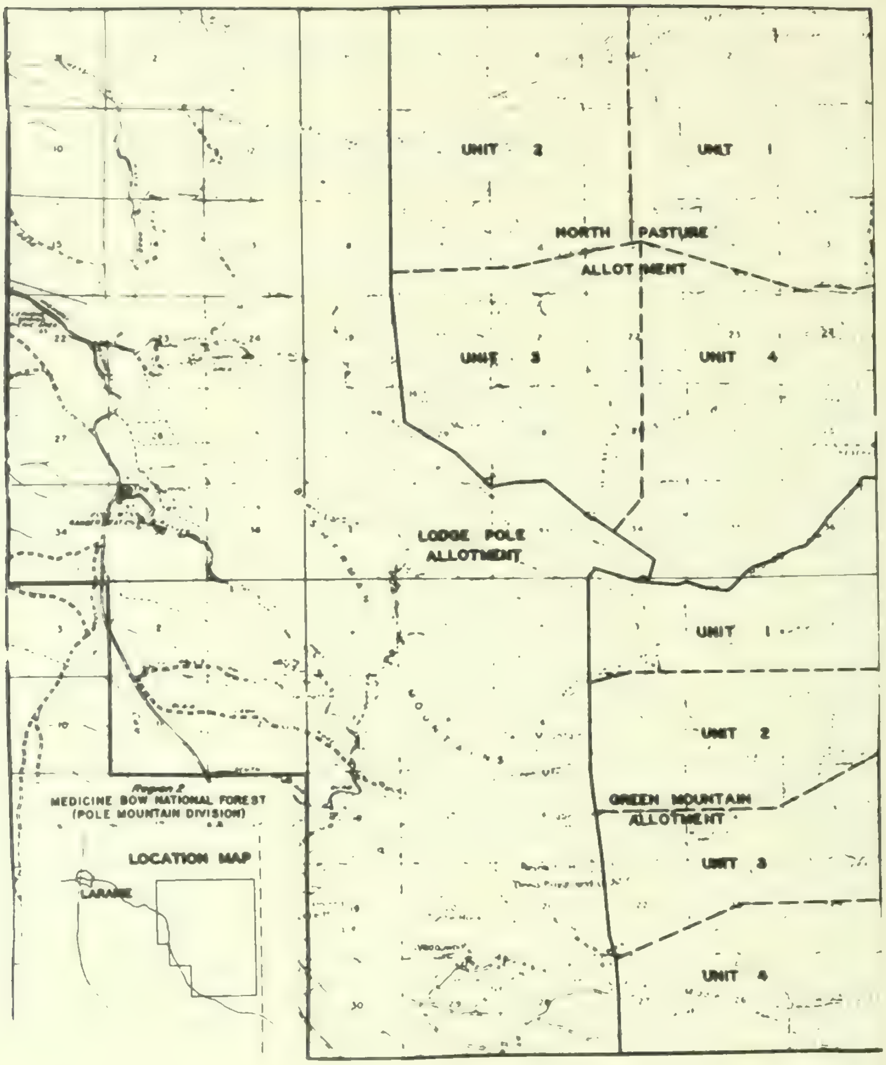

Figure 1.--[illegible] [illegible] *Allotments used in this study.*

The Lodgepole Allotment was continued under season-long management, and used as a check to help evaluate changes in utilization and vegetation on the other two allotments.

During the period of study, no changes were made in the numbers of livestock permitted to graze the allotments. Some fluctuations occurred on the Lodgepole Allotment, however, because some permittees kept their livestock on their home ranges until after the breeding season. This amounted to reductions in use of approximately 900 animal months in 1959 and 450 animal months in 1960. Permitted use on this allotment was 3,213 animal months.

Description of the Area

The North Pasture Allotment contained 16,603 acres, of which 15,548 acres were usable range. Actual grazing use from 1950 to 1958 had been 1,949 animal months per year.

On this area, only three vegetation types contributed importantly to acreage and grazing capacity. The largest (8,738 acres, fig. 2) was the grassland type, where Griffiths wheatgrass,[3] slimstem muhly, and three-tip sage-

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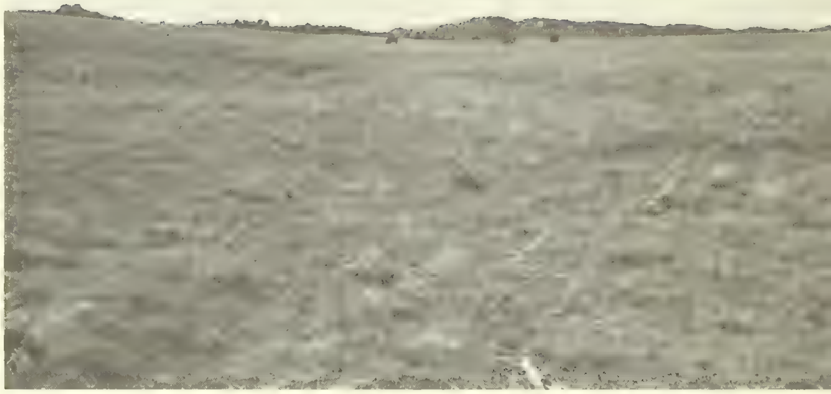
[3] *Common and botanical names of species are listed on page 15.*

Figure 2.--Grassland types occur on upland areas of gently rolling topography. Stream channels are seldom incised more than 50 to 75 feet.



brush were dominants, and prairie Junegrass, Idaho fescue, Sandberg bluegrass, and Parry danthonia were associated species.

The mixed shrub type dominated by big sagebrush, bitterbrush, and Griffiths wheatgrass occupied 2,714 acres. The same type but with an open stand of ponderosa pine occupied 2,409 acres. For evaluation purposes these two types were considered the same. Associated species were Idaho fescue, spikefescue, western wheatgrass, needle-and-thread, and sun sedge (fig. 3).

The most important species in the meadow type along the valley bottoms were various sedges and rushes, Kentucky bluegrass, tufted hairgrass, and bluejoint reedgrass. This type occupied 122 acres (fig. 4).

Observations on the North Pasture Allotment were confined to these three major vegetation types.

The Green Mountain Allotment contained 9,351 acres, of which 8,974 were usable range. Actual grazing use had been 2,250 animal months per year.

The same forage types were present as on the North Pasture Allotment, but only two of these were important from an area and graz-

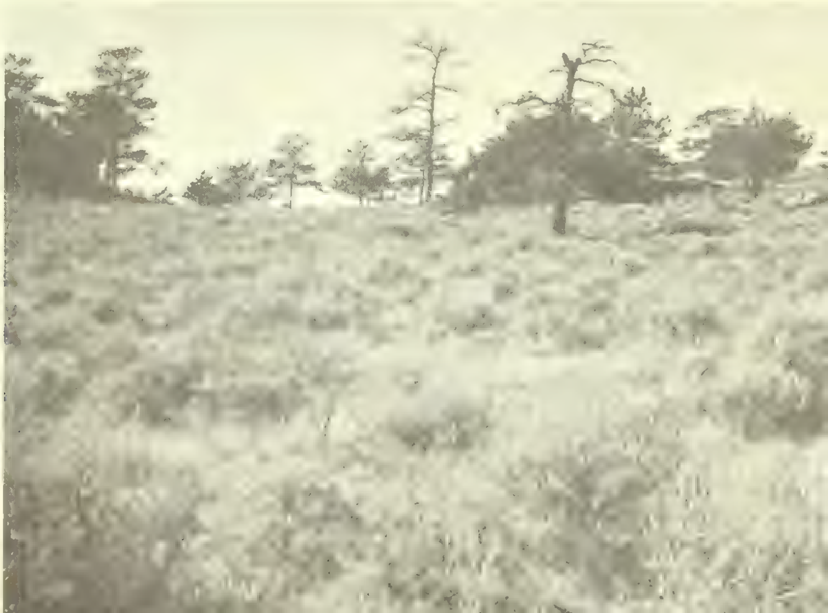


Figure 3.--The mixed shrub types occur on slightly steeper slopes than the grasslands, and are well vegetated.

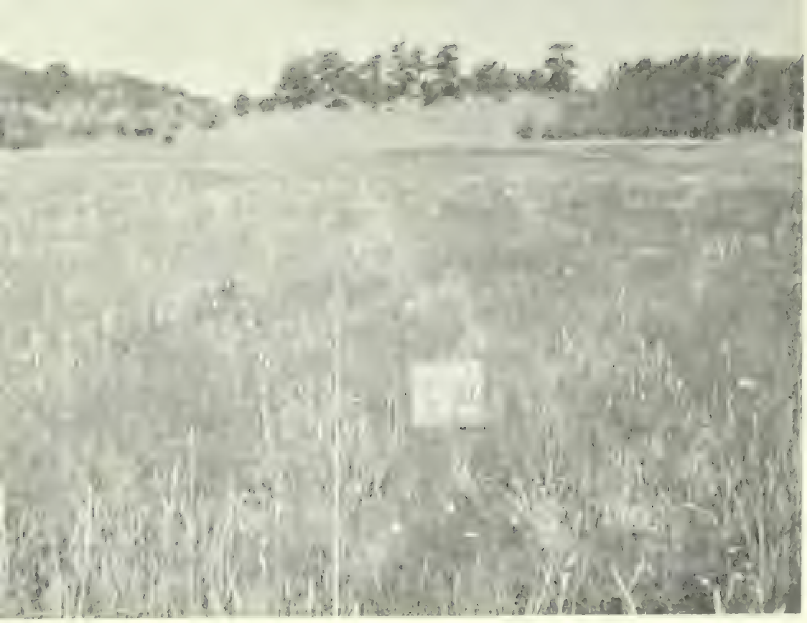


Figure 4.--Meadows vary from semi-dry and well drained to very wet and boggy areas. The boggy areas were not studied.

ing capacity standpoint--the open grasslands and the meadow types. The species composition was very similar to that on the North Pasture Allotment, but some of the more desirable grasses (Parry danthonia, spikefescue, mountain muhly, and others) were less abundant and plant vigor was much lower.

The Lodgepole Allotment joins the Green Mountain Allotment on the west and the North Pasture Allotment on the south. Only a small portion of the allotment (the northeast corner) was evaluated. The area was approximately the same size as one unit of the Green Mountain Allotment, and contained approximately the same proportion and distribution of vegetative types.

For the Green Mountain and Lodgepole Allotments, the evaluation was confined to the grassland and meadow types of vegetation.

Six locations in grassland, six in sagebrush, and six in meadow types in each of the four units in the North Pasture Allotment were studied. To better evaluate changes in plant cover, the six locations in the meadows were further categorized as "wet" and "dry" meadows. Three locations in the grassland and three in bottom types in each unit of the Green Mountain Allotment and in the study area of the Lodgepole Allotment were studied. All locations were selected to be as nearly typical of existing conditions as possible.

At each location, one cluster of two transects was established to measure changes in the vegetative cover. The 3-step method developed by Parker [4] was followed. The transects were permanently located and measured in 1958, and remeasured in 1962 and 1963. Measurements made in 1958 were considered pretreatment data. Effectiveness of the proposed management procedure was measured in terms of change from 1958 conditions.

The degree of herbage utilization was based on the percent of weight removed in relation to percent of height removed.[5] These measurements were obtained each year at the end of the grazing period on each unit.

Species selected for utilization measurement on the grassland and browse types were Griffiths wheatgrass, slimstem muhly, needle-and-thread, Idaho fescue, and sun sedge. The first two species are not considered choice forage species, but were used because the more desirable species such as mountain muhly, Idaho fescue, needle-and-thread, and

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[4] *Parker, Kenneth W. A method for measuring trend in range condition on national forest ranges. 26 pp., illus. 1951. (Unpublished report on file at U. S. Forest Serv., Washington, D. C.)*

[5] *Lommasson, T. and Jensen, Chandler. Determining utilization of range grasses from height-weight table. Jour. Forestry 41: 589-593, illus. 1943.*

Parry danthonia were not always present in sufficient abundance to measure.

On the meadows the species selected for utilization measurements were slender wheatgrass, Kentucky bluegrass, tufted hairgrass, needle-and-thread, Nebraska sedge, needleleaf sedge, and shortbeak sedge. These were considered choice forage species.

Results

Utilization on Allotments

How the system of management influences utilization was studied by comparing the use of the types during the 1956-57 period ("pretreatment"), when all allotments were grazed season-long, with the utilization during the 1958-61 period ("treatment"), when the Lodgepole Allotment was grazed season-long, and the North Pasture and Green Mountain Allotments were grazed under rotation plans. By allotments and vegetative types, the average utilization of all species, measured by percent of weight removed was as follows:

	Pretreatment 1956-57	Treatment 1958-61
Lodgepole (season-long grazing, both periods):		
Grassland	10.0	9.0
Meadow	31.6	33.0
Green Mountain (rotation grazing):		
Grassland	13.1	9.6
Meadow	41.1	16.1
North Pasture (rest-rotation grazing):		
Grassland	8.0	4.2
Meadow	28.0	17.8
Mixed browse	13.2	6.4

There was no significant change in utilization on the Lodgepole Allotment, which was grazed season-long during both the pretreatment and treatment periods.

Rotation management on the Green Mountain Allotment during 1958-61 reduced average utilization on grassland types slightly below the pretreatment level, but the reduction probably was not of practical significance. On the meadows, however, utilization during the rotation period was reduced from 41 to 16 percent. This reduction was clearly evident on all meadow areas (fig. 5). Their condition was a striking contrast to the condition of the same meadows during the pretreatment period, or to similar meadows in the Lodgepole Allotment (fig. 6).

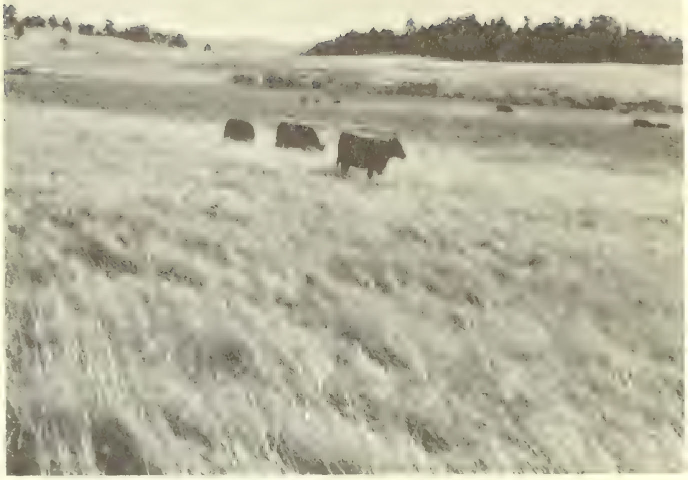
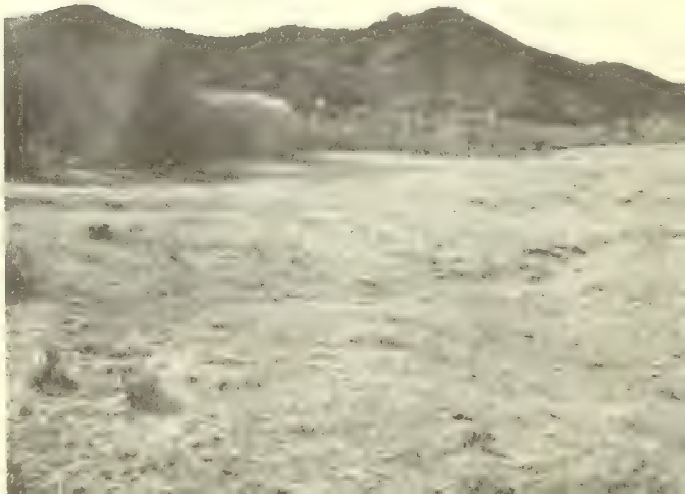


Figure 5.--At end of the season, Unit 1 of the Green Mountain Allotment clearly shows light use in the bottoms under rotation grazing.

Utilization during the rest-rotation period of management on the North Pasture Allotment was about half that received during pretreatment period of season-long grazing. The largest reduction in use (10.2 percent) was measured on the meadow types, and the least (3.8 percent) on the grassland types. There was no real change in the pattern of grazing on the different types of vegetation, but rather

Figure 6.--This close utilization of a meadow area in the Lodgepole Allotment is a characteristic of season-long grazing management.



a general decrease over all types. During the 1956-57 period, grazing tended to be concentrated in one part of the allotment and other parts were little used. Under rest-rotation management, the cattle were more equally distributed.

Utilization by Species and Units

On grassland areas in the Lodgepole Allotment, some changes in species utilization are not explainable at present. According to measurements made during the study, utilization of Griffiths wheatgrass increased (table 1), while utilization of slimstem muhly decreased.

On the meadow areas in the Lodgepole Allotment the pattern of species utilization did not change significantly. All species showed reasonably consistent degrees of use from 1957 to 1961. Nebraska sedge and slender wheatgrass carried most of the grazing; Kentucky bluegrass and shortbeak sedge were grazed moderately.

On grassland types in the Green Mountain Allotment, needle-and-thread was by far the most heavily grazed species measured (table 1). This species does reflect the reduced utilization resulting from the rotation system of management on units 1 and 2, but on units 3 and 4 utilization was heavier under rotation grazing. This change is undoubtedly related to changes in the pattern of distribution of the livestock. Average utilization of needle-and-thread under season-long grazing was 20 percent as compared with 14 percent during the rotation period.

Griffiths wheatgrass was more palatable than slimstem muhly on the two units in which it was measured as an indicator of utilization. Utilization of the wheatgrass was lower during the rotation grazing (9.0 percent) than during season-long grazing (13.5 percent).

Slimstem muhly was grazed the least of all species measured. No significant differences in utilization of this species were found between rotation and season-long grazing.

Meadows in units 2 and 3 of the Green Mountain Allotment were more heavily grazed under season-long management than the meadows in units 1 and 4 (table 1). Also, under rotation grazing utilization was more uniformly distributed over all meadows, although those in units 2 and 3 were still grazed more. Based on utilization of Kentucky bluegrass and shortbeak sedge (the only species measured on all units), the average use on units 2 and 3 prior to rotation was 66 percent and during rotation 23.5 percent, or only one-third as heavy. For units 1 and 4, average utilization prior to rotation was 29 percent and during rotation 13 percent, or only half as heavy.

Utilization of the different forage species varied considerably between the Green Mountain and Lodgepole Allotments. Shortbeak sedge was one of the most heavily grazed species on the Green Mountain Allotment, but not on the Lodgepole. Slender wheatgrass was grazed as heavily as Kentucky bluegrass on the Green Mountain allotment, but was more heavily grazed on the Lodgepole Allotment. Tufted hairgrass was very lightly utilized under rotation grazing. Reasons for these inconsistencies in species utilization are not fully understood.

On grassland areas in the North Pasture Allotment, Griffiths wheatgrass was grazed more heavily than slimstem muhly both during and prior to the rest-rotation period (table 1). Under rest-rotation grazing, utilization on Griffiths wheatgrass averaged 5.5 percent as compared with 9.1 percent under season-long grazing; utilization of slimstem muhly averaged 2.9 percent under rest-rotation grazing and 6.8 percent under season-long grazing.

On the mixed-browse type in the North Pasture Allotment, needle-and-thread was the most heavily utilized species under both season-long and rest-rotation grazing. Idaho fescue ranked next under season-long grazing, but sun sedge ranked second under rest-rotation. Utilization of sun sedge and slimstem muhly were about equal at the beginning of the study, but use of the latter decreased considerably under the rest-rotation system whereas the use on sun sedge did not. Griffiths wheatgrass was grazed least in the initial period, but was more palatable than slimstem muhly during the rest-rotation period.

Table 1.--Average utilization by species, units, and grazing systems, during pretreatment period (1956-57) when all units were grazed season-long, and treatment period (1958-61) when Lodgepole Allotment was grazed season-long, Green Mountain by rotation, and North Pasture by rest-rotation

Allotment, unit, vegetative type, and species	Pretreatment 1956-57	Treatment 1958-61
	Pct. weight removed	
LODGEPOLE ALLOTMENT		
Grasslands:		
Griffiths wheatgrass	8.5	14.0
Slimstem muhly	11.5	4.1
Meadows:		
Slender wheatgrass	30.5	36.5
Kentucky bluegrass	27.0	24.6
Nebraska sedge	47.0	45.6
Shortbeak sedge	22.0	25.3
GREEN MOUNTAIN ALLOTMENT		
Grasslands:		
Unit 1 Griffiths wheatgrass	11.0	5.4
Slimstem muhly	1.5	4.9
Needle-and-thread	31.0	14.8
Unit 2 Slimstem muhly	8.8	3.0
Needle-and-thread	25.5	10.6
Unit 3 Griffiths wheatgrass	16.0	12.5
Needle-and-thread	12.0	18.6
Unit 4 Slimstem muhly	1.5	4.4
Needle-and-thread	10.5	12.0
Meadows:		
Unit 1 Slender wheatgrass	28.0	12.1
Kentucky bluegrass	21.0	10.0
Shortbeak sedge	20.5	14.1
Unit 2 Kentucky bluegrass	67.0	16.8
Shortbeak sedge	77.0	20.0
Unit 3 Kentucky bluegrass	58.0	26.6
Shortbeak sedge	60.0	30.4
Unit 4 Slender wheatgrass	33.5	15.0
Kentucky bluegrass	23.0	15.0
Tufted hairgrass	31.5	4.4
Shortbeak sedge	32.5	12.9
NORTH PASTURE ALLOTMENT[1]		
Grasslands:		
Unit 1 Griffiths wheatgrass	9.5	5.0
Slimstem muhly	5.8	3.0
Unit 2 Griffiths wheatgrass	10.5	6.8
Slimstem muhly	7.5	3.8
Unit 3 Griffiths wheatgrass	9.3	6.7
Slimstem muhly	8.8	4.0
Unit 4 Griffiths wheatgrass	7.0	3.7
Slimstem muhly	5.3	.7
Mixed browse:		
Unit 1 Griffiths wheatgrass	7.6	5.8
Slimstem muhly	12.0	3.8
Unit 2 Griffiths wheatgrass	7.0	5.5
Slimstem muhly	10.3	6.0
Idaho fescue	16.0	7.5
Unit 3 Griffiths wheatgrass	8.8	6.2
Slimstem muhly	11.3	3.0
Idaho fescue	9.0	4.5
Sun sedge	12.5	11.2
Unit 4 Griffiths wheatgrass	7.3	5.5
Slimstem muhly	15.0	2.3
Idaho fescue	24.0	3.3
Needle-and-thread	31.5	18.0
Meadows:		
Unit 1 Needle-and-thread	17.4	24.0
Kentucky bluegrass	30.5	15.8
Nebraska sedge	32.9	13.3
Shortbeak sedge	34.0	11.7
Needleleaf sedge	12.0	12.2
Unit 2 Needle-and-thread	33.8	26.3
Kentucky bluegrass	44.0	17.0
Nebraska sedge	29.3	30.2
Shortbeak sedge	22.5	17.8
Needleleaf sedge	9.0	13.2
Unit 3 Slender wheatgrass	33.0	18.8
Needle-and-thread	44.0	25.2
Nebraska sedge	28.3	20.7
Shortbeak sedge	34.3	12.7
Needleleaf sedge	13.0	5.0
Unit 4 Needle-and-thread	39.8	37.3
Nebraska sedge	26.3	16.8
Shortbeak sedge	32.3	10.0
Needleleaf sedge	15.8	10.7

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[1] Rest-rotation grazing: average of years of actual use only.

Table 2.--Average utilization by species and period of use during treatment period, 1958-61, on Green Mountain Allotment (rotation grazing) and North Pasture (rest-rotation grazing)

Allotment and vegetative type	Species	First period	Second period	Third period	Fourth period
		Percent weight removed			
GREEN MOUNTAIN ALLOTMENT:					
Grasslands	Griffiths wheatgrass	7.0	8.5	8.5	12.0
	Slimstem muhly	3.3	7.3	3.8	1.8
	Needle-and-thread	11.3	17.0	18.6	9.1
	Average	7.2	10.9	10.3	7.6
Meadows	Slender wheatgrass	13.0	5.5	13.0	22.8
	Kentucky bluegrass	17.8	23.1	15.3	12.5
	Tufted hairgrass[1]	7.5	1.5	6.5	2.2
	Shortbeak sedge	21.5	20.5	20.0	15.4
	Average	14.9	12.6	13.7	13.2
NORTH PASTURE ALLOTMENT:					
Grasslands	Griffiths wheatgrass	3.8	6.4	6.5	([2])
	Slimstem muhly	2.5	3.4	2.6	([2])
	Average	3.2	4.9	4.6	([2])
Mixed browse	Griffiths wheatgrass	4.1	6.1	7.0	([2])
	Slimstem muhly	2.6	4.9	3.9	([2])
	Idaho fescue	2.5	3.1	5.9	([2])
	Needle-and-thread	36.0	17.0	1.0	([2])
	Sun sedge[1]	5.0	9.0	19.5	([2])
	Average	10.0	8.0	7.5	([2])
Meadows	Slender wheatgrass[1]	7.5	27.0	22.0	([2])
	Kentucky bluegrass	6.8	15.0	27.5	([2])
	Needle-and-thread	26.0	22.6	36.0	([2])
	Needleleaf sedge	8.3	8.8	13.8	([2])
	Shortbeak sedge	12.4	13.0	13.8	([2])
	Nebraska sedge	13.8	21.4	25.6	([2])
	Average	12.5	18.0	23.1	([2])

[1] Occurred on one unit only.

[2] Rest period; no grazing.

With season-long use on the meadows of the North Pasture Allotment, relative utilization of the species studied varied considerably. For example, needle-and-thread was very lightly utilized in unit 1 (17.4 percent) but was the most heavily grazed species in unit 3 (44 percent, table 1). Utilization on all species except needleleaf sedge averaged between 29.2 percent (Nebraska sedge) and 37.2 percent (Kentucky bluegrass), however, which indicates that for the whole allotment there was little difference among the species. Needleleaf sedge was only grazed an average of 12.4 percent.

During the rest-rotation period of grazing, variation in utilization for the different species was shown more clearly. Based on average utilization the ratings were as follows:

	Percent
Season-long:	
Kentucky bluegrass	37.2
Needle-and-thread	33.8
Slender wheatgrass	33.0
Shortbeak sedge	30.8
Nebraska sedge	29.2
Needleleaf sedge	12.4
Rest-rotation:	
Needle-and-thread	28.2
Nebraska sedge	20.2
Slender wheatgrass	18.8
Kentucky bluegrass	16.4
Shortbeak sedge	13.0
Needleleaf sedge	10.3

Utilization by Period of Use

The time of year that an area was grazed had little effect on the intensity of utilization on grassland types. This was true on both the Green Mountain and North Pasture Allotments (table 2). There was some indication that the cattle grazed the upland areas more heavily in midsummer than either earlier or later in the year, but the differences are not significant. Greater freedom from flies because of the almost constant winds on the upland areas may have been responsible for the slight preference cattle exhibited for these areas during midsummer.

On the more heavily stocked Green Mountain Allotment there was no significant difference in the average utilization of the meadow types as related to time of grazing. On the lightly stocked North Pasture, however, utilization was lightest during the early part of the season. Utilization was heaviest during the last period of grazing, September 1 to October 15, probably because the meadow vegetation stayed green late into the season.

The mixed-browse type in the North Pasture Allotment was grazed most heavily during the first period, June 1 to July 16. These areas provide good shelter during the cold storms and winds that occur frequently during this period.

The utilization of individual species in relation to time of grazing was highly variable and, in certain instances, inconsistent. Whenever Griffiths wheatgrass was used as an indicator of utilization, however, it was used most heavily during the last period of grazing. Needle-and-thread was grazed most heavily in the mixed-browse type during the early summer, in the grassland types in midsummer, and in meadow types in late summer. Use on slender wheatgrass, Kentucky bluegrass, and tufted hairgrass was also inconsistent. In general, the sedges were grazed most heavily late in the season.

From these studies it would appear that grazing use of different vegetation types and of individual species of plants is related more to the needs and preference of the animal than to the time of year the range is grazed.

Changes in Plant Cover

Plant cover did change during the period of study. Transect measurements, by number of hits per 100-foot transect, in 1958 and again in 1962 showed the following changes in vegetative cover by three methods of range management:

	Original 1958	Change 1962
Lodgepole (season-long grazing, both periods):		
Wet bottoms	78	+ 5
Grasslands	43	+ 4
Green Mountain (rotation grazing):		
Wet bottoms	77	+10
Grasslands	60	- 1
North Pasture (rest-rotation grazing):		
Wet bottoms	76	+15
Dry bottoms	61	+20
Grassland	46	+12
Mixed shrub	29	+13

In the wet-meadow type in the Lodgepole Allotment, the number of loops that contained living plants increased 6 percent. The same type on the Green Mountain Allotment showed an increase of 13 percent.

In the wet-meadow types on the North Pasture Allotment, the number of loops containing vegetation increased 20 percent (fig. 7). The increase was even greater (33 percent) on the dry-meadow types in this allotment.

The upland types in the Lodgepole and Green Mountain Allotments showed no significant change in the number of loops containing vegetation. On the North Pasture Allotment, however, the number of loops containing vegetation increased 26 percent (fig. 8).

Mixed-browse types in the North Pasture Allotment also improved--the number of loops containing vegetation increased 45 percent.

These gross changes in the vegetative cover were comprised of small changes in many species. In the meadow type on the Lodgepole Allotment, the largest species change was an average increase of 17.3 hits per transect (table 3) for Kentucky bluegrass. Tufted hairgrass and rose pussytoes increased 4.0 and 4.5 hits per transect, respectively. Some species decreased in abundance. The largest decreases were recorded for prairie Junegrass, mat muhly, sedges (other than Nebraska sedge), and decumbent goldenrod.

On the Green Mountain Allotment, the only change measured of any real magnitude was an increase of 5.1 hits per transect on Kentucky bluegrass. This was also true on the meadows in the North Pasture Allotment, where Kentucky bluegrass increased 5.7 hits per transect. Some other species did show increases, but of smaller magnitude--slender wheatgrass, prairie Junegrass, alpine timothy, and needle-and-thread all increased within a range from 1.2 to 2.6 hits per transect. There were no significant decreases in any of the species on either Green Mountain or the North Pasture Allotments. The largest decrease was 1.7 hits on Baltic rush in the Green Mountain Allotment.

In the grassland type, large decreases in number of hits per transect were noted on the Lodgepole Allotment for both three-tip sagebrush and selaginella (table 3). Slimstem muhly also decreased, but not as much. Small but important increases were noted for prairie Junegrass. No significant changes occurred in species hits on the Green Mountain Allotment. On the North Pasture Allotment the changes in species hits also were small. The greatest changes took place in three-tip sagebrush (+2.1), prairie Junegrass (+1.9), slimstem muhly (+1.5), and rose pussytoes (+1.5). It is important, however, that almost all species did increase in number of hits per transect, and on these poor soils and dry sites such changes could be interpreted as an improvement in the vegetative cover.

In the mixed-browse type on the North Pasture Allotment, no species decreased in number of hits per transect. Average increase in the number of hits per 100 observations between 1958 and 1962 by species was:

Griffiths wheatgrass	1.3
Parry danthonia	.1
Idaho fescue	1.3
Spikefescue	.1
Prairie Junegrass	.9
Slimstem muhly	1.1
Mountain muhly	.2
Sandberg bluegrass	2.4
Needle-and-thread	.1
Sedges	.4
Rose pussytoes	.4
Sandwort	.1
Subalpine eriogonum	.4
Big sagebrush	.6
Bitterbrush	2.3

Griffiths wheatgrass, Idaho fescue, Sandberg bluegrass, and antelope bitterbrush all increased appreciably. Other species changes were small.

Discussion

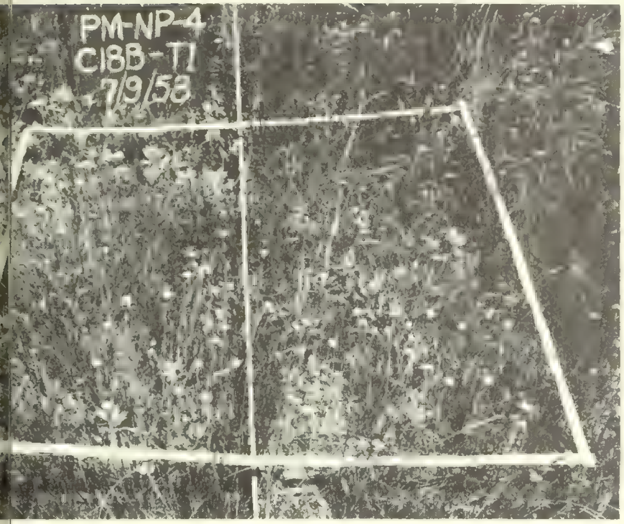
Results of this study indicate that either rotation or rest-rotation systems of management can benefit cattle ranges. The most striking result is reduced utilization without any reduction in the number of animals grazed. The rotation system on the Green Mountain Allotment resulted in much greater decreases in utilization on the meadow types than the rest-rotation system on the North Pasture Allotment. This does not necessarily mean that the rotation system is better than the rest-rotation system. Both stocking rates and utilization were lighter on the North Pasture Allotment to begin with, so the opportunity for reductions were not so great. Hormay

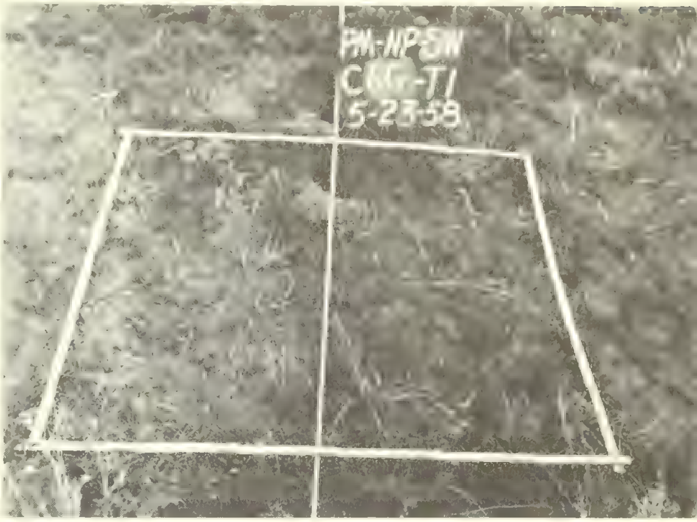
NORTH PASTURE ALLOTMENT

(Rest-rotation management)

MEADOW TYPE

GRASSLAND TYPE



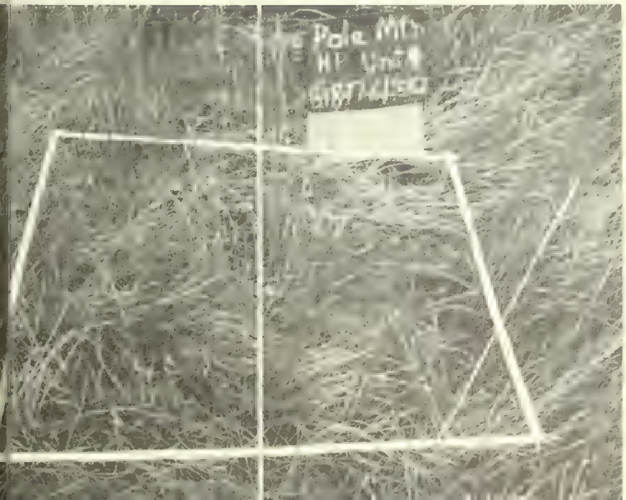


BEFORE TREATMENT (1958)

igure 7.--Grasses have increased and forbs decreased on this same spot in Unit 4. Vegetation increased 20 percent in wet meadows and 33 percent in dry meadows.

Figure 8.--Vegetation increased 26 percent on this same spot in Unit 3. Grasses are more numerous and more vigorous.

AFTER TREATMENT (1962)



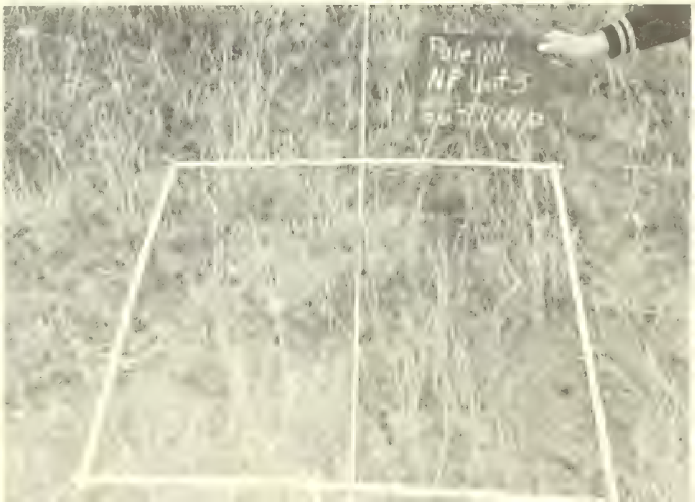


Table 3.--Change in frequency of species occurrence, by vegetative type, as a result of three methods of grazing management on three allotments of the Pole Mountain unit, Medicine Bow National Forest, Wyoming, 1958-62

Vegetative type	Species	Lodgepole Allotment (Season-long)	Green Mountain Allotment (Rotation)	North Pasture Allotment (Rest-rotation)
		Average change in number of hits per 100 observations		
Grasslands	Griffiths wheatgrass	+1.2	-0.1	+0.7
	Blue grama	-1.5	+ .9	- .1
	Parry danthonia	--	- .1	+ .01
	Idaho fescue	--	- .04	+ .2
	Prairie Junegrass	+2.9	- .1	+1.9
	Slimstem muhly	-2.7	-1.0	+1.5
	Sandberg bluegrass	+1.1	+ .7	+1.3
	Needle-and-thread	+ .4	- .4	- .1
	Sedges	+ .7	+ .5	+ .1
	Rose pussytoes	+ .2	+ .5	+1.5
	Sandwort	+ .9	+ .04	+ .4
	Phlox	+ .2	--	+ .3
	Loco	--	--	- .05
	Selaginella	-3.6	-1.0	+ .9
	Fringed sagebrush	- .4	-1.2	+ .5
	Three-tip sagebrush	-8.7	+ .1	+2.1
Meadows	Slender wheatgrass	-2.5	+0.2	+2.6
	Tufted hairgrass	+4.0	- .8	- .2
	Prairie Junegrass	-3.2	+1.2	+1.7
	Mat muhly	-3.9	-1.8	- .5
	Alpine timothy	+ .5	+1.1	+1.2
	Kentucky bluegrass	+17.3	+5.1	+5.7
	Sandberg bluegrass	-1.7	+ .3	+1.1
	Needle-and-thread	+ .3	+ .8	+2.3
	Nebraska sedge	+ .3	- .3	+ .3
	Sedges	-3.6	-2.6	- .9
	Rush	- .2	-1.7	+1.0
	Yarrow	+ .8	- .3	- .3
	Rose pussytoes	+4.5	+ .9	- .9
	Decumbent goldenrod	-4.5	+ .1	+ .2
	Dandelion	- .3	+ .3	+1.0
	Fringed sagebrush	+ .4	- .6	- .2

and Talbot[6] believe, "Fairly heavy stocking is desirable in rest-rotation grazing"; this is certainly true if maximum benefits are to be obtained from the system. On the North Pasture Allotment, the stocking rate was estimated to be about 50 percent of capacity at the start of the study. Green Mountain, on the other hand, was estimated to need a 50 percent reduction in numbers under season-long use to achieve proper use of the bottoms.

Reasons for reduced utilization without reduction in livestock numbers have not been fully determined. Several factors may be involved: (1) increased total production of herbage because of increased plant vigor; (2) growth and production of herbage are allowed to get "ahead of the cattle" each year on all but one unit in either system of management, and (3) the previous year's regrowth after grazing is mixed with the current year's growth, which provides more bulk in the diet. Other factors not yet recognized may also be important.

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[6] *Hormay, A. L. and Talbot, M. W. Rest-rotation grazing...A new management system for perennial bunchgrass ranges. U. S. Dept. Agr. Prod. Res. Rpt. 51, 43 pp., illus. 1961.*

Another important result was the more uniform distribution of grazing use over the entire allotment. Again, the rotation system on Green Mountain illustrates this improved uniformity most clearly because of the heavier utilization involved. Under season-long grazing, the meadows in two of the units were carrying most of the grazing load. The rotation system spread this load more uniformly over all the units. Similarly, needle-and-thread in the grassland type was being most heavily grazed on two units under season-long use. Under the rotation system, use on this grass decreased on these units but increased on the two units where it had previously been very light. Similar trends toward more uniform use over the whole allotment were present but in much lesser magnitude on the North Pasture Allotment under the rest-rotation system of management.

Total plant cover definitely changed during the 4 years of the rotation period. The changes were of greatest magnitude under the rest-rotation system for all types for which comparisons were available. The increase in cover on meadow types amounted to 20 percent, 13 percent, and 6 percent for the rest-rotation under light stocking, rotation under heavy stocking, and season-long under moderate stocking, respectively. Corresponding increases on the grassland type were 26 percent, -2 percent (decrease), and 9 percent in the same order. For this area, which has relatively low-fertility granitic soils with poor water-holding capacity, and semiarid and windy climate, changes of this magnitude during a 4-year period are somewhat surprising.

The changes in frequency of individual species were small, and except for Kentucky bluegrass were probably insignificant except for the consistency with which they indicate a trend. These changes were most pronounced in the meadow types.

Although Kentucky bluegrass is a good forage species, and in many instances may be more desirable than some native species, it is definitely an invader and known to increase under heavy grazing. This plant increased on all allotments, but the increase on the one used season-long was more than three times as much as on either of the other two allotments. Some of this increase occurred at the expense of good native forage species (fig. 9).

Three poor forage species--rose pussytoes, fringed sagebrush, and yarrow--commonly accepted indicators of range deterioration, increased on the allotment grazed season-long but decreased (or made very slight increase) on the rest-rotation and rotation allotments.

A group of good forage species--slender wheatgrass, Sandberg bluegrass, prairie Junegrass, and decumbent goldenrod--all decreased on the season-long allotment but increased under the other two systems of management.

A group of sedges, all of which are good forage species, decreased on all three allotments. The greatest decrease, however, occurred on the season-long allotment and the least on the rest-rotation allotment.

When one rationalizes these changes in cover, it appears obvious that a system of rest-rotation management will stimulate range improvement more rapidly than a simple rotation system, but either method will be more beneficial to the range than the customary practice of grazing season-long.

Rotation or rest-rotation systems of management cannot be initiated without encountering some difficulties. The most frequent problem is concentration of use along fence lines. Whenever livestock, especially cows with calves, are forced to give up their established and preferred grazing areas on an allotment they will "fight the fences" trying to get to those preferred areas. This results in excessive trampling and use along the fence lines. Fortunately, this situation exists only during the first year; by the second year the animals have adjusted to their new grazing areas and

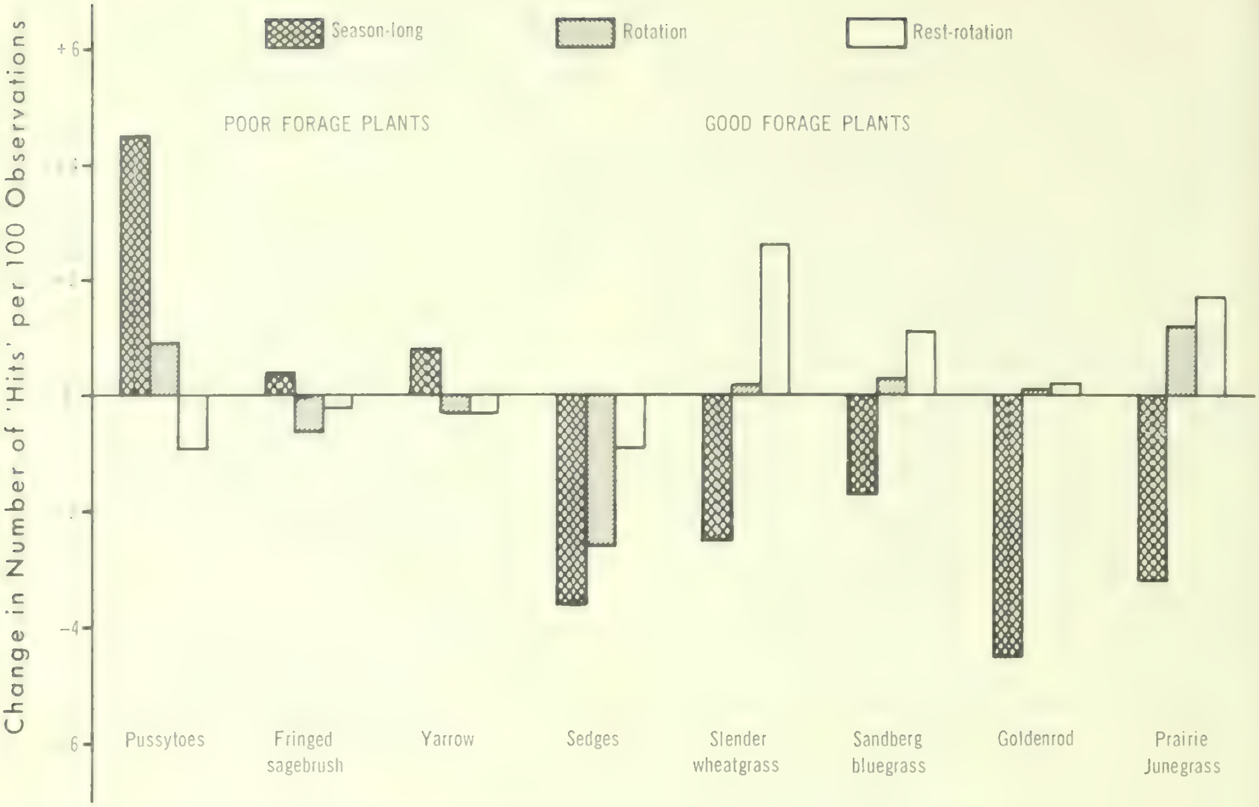

Figure 9.--Changes in the occurrence of selected native species in relation to type of grazing management, meadow types, Pole Mountain 1958-62.

the problem is eliminated. This situation actually developed on the North Pasture Allotment during the first year of rotation.

Another common problem is the failure to equalize grazing capacities in units within the allotments. This is not serious unless the differences are great. An adjustment in the number of days of grazing will generally correct this situation. As Hormay and Talbot[6] have stated, however, ''In effect, grazing is eliminated as an environmental factor under rest-rotation grazing.'' This means that the range manager using an adequately planned system of rest-rotation grazing need not be as concerned about heavy rates of utilization.

Rotation and rest-rotation systems of management have sufficient flexibility to meet most range conditions. Properly planned and executed they can be beneficial. They must, however, be planned so that the physiological needs of the vegetation are most effectively met.

COMMON AND BOTANICAL NAMES OF SPECIES MENTIONED

Bitterbrush, antelope	*Purshia tridentata* (Pursh) DC.
Bluegrass, Kentucky	*Poa pratensis* L.
Bluegrass, Sandberg	*Poa secunda* Presl.
Dandelion	*Taraxacum* spp.
Danthonia, Parry	*Danthonia parryi* Scribn.
Eriogonum, subalpine	*Eriogonum subalpinum* Greene
Fescue, Idaho	*Festuca idahoensis* Elmer
Goldenrod, decumbent	*Solidago decumbens* Greene
Grama, blue	*Bouteloua gracilis* (H.B.K.) Lag.
Hairgrass, tufted	*Deschampsia caespitosa* (L.) Beauv.
Junegrass, prairie	*Koelaria cristata* (L.) Pers.
Loco	*Astragalus* spp.
Muhly, mat	*Muhlenbergia richardsonis* (Trin.) Rydb.
Muhly, mountain	*Muhlenbergia montana* (Nutt.) Hitchc.
Muhly, slimstem	*Muhlenbergia filiculmis* Vasey
Needle-and-thread	*Stipa comata* Trin. & Rup.
Phlox	*Phlox* spp.
Pine, ponderosa	*Pinus ponderosa* Lawson
Pussytoes, rose	*Antennaria rosea* (D. C. Eaton) Greene
Reedgrass, bluejoint	*Calamagrostis canadensis* (Michx.) Beauv.
Rush, Baltic	*Juncus balticus* Willd.
Sagebrush, big	*Artemisia tridentata* Nutt.
Sagebrush, fringed	*Artemisia frigida* Willd.
Sagebrush, three-tip	*Artemisia tripartita* Rydb.

Sandwort	*Arenaria* spp.
Sedge, Nebraska	*Carex nebraskensis* Dewey
Sedge, needleleaf	*Carex eleocharis* Bailey
Sedge, shortbeak	*Carex simulata* Mack.
Sedge, sun	*Carex heliophila* Mack.
Selaginella	*Selaginella densa* Rydb.
Spikefescue	*Hesperochloa kingii* (S. Wats.) Rydb.
Timothy, alpine	*Phleum alpinum* L.
Wheatgrass, Griffiths	*Agropyron griffithsii* (Scribn. & Smith)
Wheatgrass, slender	*Agropyron trachycaulum* (Link) Malte
Wheatgrass, western	*Agropyron smithii* Rydb.
Yarrow	*Achillea lanulosa* Nutt.

Johnson, W. M.
1965. Rotation, rest-rotation, and season-long grazing on a mountain range in Wyoming. U. S. Forest Serv. Res. Paper RM-14, 16 pp., illus. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Either rotation or rest-rotation systems of management were superior to season-long grazing. Plant cover increased under rest-rotation grazing, and was maintained on an overstocked allotment under rotation grazing. Range deteriorated under season-long grazing. Herbage utilization was reduced under both the rest-rotation and rotation systems without reducing numbers of livestock.

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